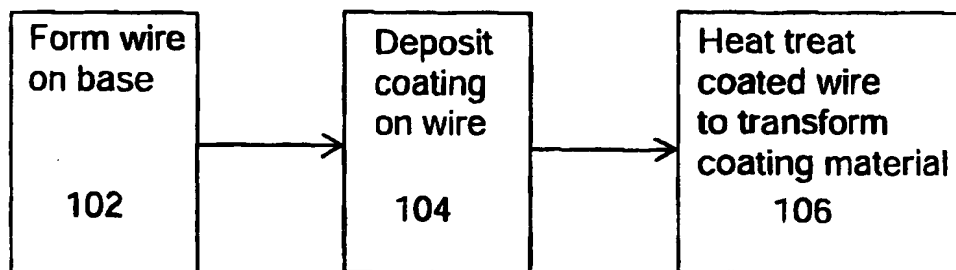




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<b>(21) International Application Number:</b> PCT/US98/12094 <b>(22) International Filing Date:</b> 11 June 1998 (11.06.98) <b>(30) Priority Data:</b> 08/931,923 17 September 1997 (17.09.97) US <b>(71) Applicant (for all designated States except US):</b> FORMFAC- TOR, INC. [US/US]; 5666 La Ribera Street, Livermore, CA 94550 (US). <b>(72) Inventors; and</b> <b>(75) Inventors/Applicants (for US only):</b> CHEN, Jimmy, Kuo-Wei [US/US]; 4854 Braxton Place, Pleasanton, CA 94566 (US). ELDRIDGE, Benjamin, N. [US/US]; 651 Sheri Lane, Danville, CA 94526 (US). DOZIER, Thomas, H. [US/US]; 5801 Ariene Way, Livermore, CA 94550 (US). YEH, Junjye, J. [-/US]; 2511 Bess Avenue, Livermore, CA 94550 (US). HERMAN, Gayle, J. [US/US]; 3362 Blackhawk Meadow Drive, Danville, CA 94506 (US). KHANDROS, Igor, Y. [US/US]; 25 Haciendas Road, Orinda, CA 94563 (US). <b>(74) Agents:</b> OKAMOTO, James, K. et al.; Fenwick & West LLP, Two Palo Alto Square, Palo Alto, CA 94306 (US).		<b>(81) Designated States:</b> AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i>

**(54) Title:** METHOD OF MAKING A STRUCTURE WITH IMPROVED MATERIAL PROPERTIES BY MODERATE HEAT TREATMENT OF A METAL DEPOSIT

**(57) Abstract**

Deposition of metal in a preferred shape, including coatings (206) on parts (204), or stand-alone materials (300), and subsequent heat treatment (106) to provide improved mechanical properties. In particular, the method gives products with relatively high yield strength. The products often have relatively high elastic modulus, and are thermally stable, maintaining the high yield strength at temperatures considerably above 25 °C. This technique involves depositing a material (206) in the presence of a selected additive, and then subjecting the deposited material to a moderate heat treatment (106). This moderate heat treatment differs from other commonly employed "stress relief" heat treatments in using lower temperatures and/or shorter times, preferably just enough to reorganize the material to the new, desired form. For example, coating and heat treating a spring-shaped elongate member provides a resilient, conductive contact (212, 920, 1060) useful for electronic applications.

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## METHOD OF MAKING A STRUCTURE WITH IMPROVED MATERIAL PROPERTIES BY MODERATE HEAT TREATMENT OF A METAL DEPOSIT

### I. Cross-References to Related Applications

5 This patent application is a continuation in part of copending U.S. patent application serial number 08/931,923, filed on 17 September 1997. This application also is a continuation-in-part of copending U.S. patent application serial number 08/452,255, filed on 26 May 1995.

### 10 II. Background of the Invention

#### 1. Technical Field

This invention relates to depositing a material into a selected shape then modifying the initial material to provide desirable mechanical properties. A suitable material deposited in an amorphous structure is heated under moderate conditions to give a more ordered structure with higher resilience, elastic modulus and temperature stability under stress. In particular, a 15 shaped material or a variety of forms may be coated with the new material and heat treated to give a shaped, hardened coating, particularly in the form of a conductive spring.

#### 2. Description of Related Art

20 The concept of applying a coating to impart desirable mechanical properties is used in many fields, from semiconductors to automobiles. For example, micro-electromechanical structures, microelectronic packaging, and magnetic storage media all employ such coatings. A variety of processes from sputtering to electroforming to chemical vapor deposition are widely used to fabricate such coatings. However, the mechanical properties of many of these 25 coatings are not completely stable, especially at elevated temperatures. This is especially true for deposition processes that result in a non-equilibrium structure. Thus parts with these coatings have a fundamental problem in applications which require stable mechanical properties under load, particularly at elevated temperatures.

Annealing, or heating a material at a significantly elevated temperature for an extended 30 period of time, is generally recognized as a way to bring a structure more into equilibrium. Annealing is often used to relieve brittleness. Brittleness often results from various material-forming processes. For example, in forming a wire, it is common to extrude the material through a die, which involves various compression and deformation processes. The wire as

extruded has the desired shape, but examination of the microstructure of the material reveals large amounts of internal stresses as internal stress fields. If these internal stress fields are high, the material might be considered to be brittle, and will break under moderate applied stresses. Heat treating such a wire will allow the material to reorganize and relieve these  
5 internal stress fields.

Heat treatment also is used to redistribute components within a system. For example, it is common in semiconductor processing to apply a dopant such as boron or phosphorous on the surface of a silicon substrate. Heating, or annealing, this product allows redistribution of the dopant atoms within the silicon structure as the dopant atoms diffuse within the base  
10 material.

Annealing of metal coatings such as nickel (Ni) also is common in many plating operations. It is quite common to electroplate nickel on a substrate, then anneal at, for example, 700° C for one to two hours. This is generally to relieve essentially all stress in the coating, so the annealing is continued for a relatively long time and/or at a relatively high  
15 temperature. In traditional applications, nickel is plated relatively quickly, which gives a relatively disordered initial structure, which in turn provides many sources for residual stress fields. Annealing allows the material to reach an equilibrium structure, which is much more stable.

Note that a typical annealing heat treatment involves both time and temperature and  
20 one skilled in the art can balance higher temperatures against shorter times or vice versa.

Another traditional process is the preparation of thin films for hard disk or other recording surfaces. A thin film of material such as NiP is deposited on a substrate, then annealed to give a hard material.

As semiconductor technology advances and the density of devices on chips increases,  
25 increased demands are placed on electrical interconnections in microelectronics packaging and microelectronics diagnostics. The mechanical properties of such interconnections are important in achieving reliable packaging and diagnostic solutions.

For example, it is typically desirable for such interconnections to have some resiliency. Currently, commonly used technologies in microelectronics packaging exhibit little  
30 or no resiliency. Typical packaging includes wirebonding, tape automated bonding (TAB), solder bump technology, pin-in-hole solder, pin brazing, and surface-mount solder. While "pogo" pins used in microelectronics diagnostics are designed to have a resilient mechanical

structure, their substantial inductance inhibits the use of high frequency signals by the diagnostics system.

Other resilient structures useful in microelectronics include a class of structures known as micro-electronic mechanical structures or MEMS. A number of researchers have fabricated small structures such as horizontal beams positioned with other electronic components to make devices such as relays. A variety of gears and other mechanical structures have been prepared.

Before the present invention, there was perceived a need to form strong, resilient microstructures but there was no technology that would allow this. Forming microstructures directly from a resilient material is in general quite difficult, if not impossible, in that a resilient material resists specific shaping methods. For example, a tungsten needle in a conventional probe card can be bent at about a 90° angle, positioned, then cut to length, but subtler shaping is extremely difficult.

Before the present invention, it was not possible to plate a coating on a substrate of small (tens to hundreds of microns) or even large (millimeters, centimeters, or larger) minimum feature size to provide resilient characteristics, particularly where it was desirable to have a structure with good yield strength. This limitation was particularly troublesome when the device was intended for use at moderately elevated temperatures, temperatures in excess of 100°C, 85° or even 50°C. Conventional coatings could not be used to create durable, strong spring structures due to the thermal instability of the resulting coated products. The lack of structures with useful mechanical properties made it extremely difficult to build devices with large numbers of small springs, devices such as a probe card.

Early work in formable microstructures showed that a soft material such as gold could be shaped readily, then plated to give a hard coating and a resilient structure. See United States Patent No. 5,476,211, issued 19 December 1995, assigned to FormFactor, Inc., entitled "Method of Manufacturing Electrical Contacts, Using a Sacrificial Member." The work that lead to the present invention showed that use of improved materials, and subsequent heat treatment could provide a strong, resilient final product. The use of these same or similar materials together with appropriate heat treatment can provide a resilient structure in a wide variety of applications.

Plating techniques in general are well known. See, for example, United States Patent No. 4,439,284, "Composition Control of Electrodeposited Nickel-Cobalt Alloys." However, the selection of plating materials and the heat treatment conditions disclosed herein have not been disclosed in the past, in the '284 patent or elsewhere.

One skilled in the art will recognize other applications in which a material with high yield strength would be beneficial. This is particularly true for base materials with an arbitrary and possibly complex shape where retention of that shape is important, or where the base material does not have a sufficiently high yield strength. In particular, when making various spring structures of equivalent geometry and scale, an increase in elastic modulus will increase the spring value proportionally. For a fine-pitch interconnect, achieving greater spring value in a fixed volume is beneficial.

### III. Summary of the Invention

The new invention solves the traditional problem of older materials that do not provide stable mechanical properties under load, particularly at elevated temperatures. The general technique allows fabrication of coatings on parts, or stand-alone coatings, with improved mechanical properties, even at elevated operating temperatures. In particular, the method gives products with a relatively high yield strength, relatively high elastic modulus and improved temperature stability, that is, resistance to deformation under load at elevated temperatures. This technique involves depositing a coating in a selected state, and then subjecting the coating to a moderate heat treatment. This moderate heat treatment differs from other commonly employed "stress relief" heat treatments in using a combination of significantly less temperature and/or times. Traditional annealing heat treatment warms the material to a temperature and for a time to relieve essentially all stress after a subsequent cooling. The new technique takes the as-coated material to a more moderate temperature and/or for a shorter time, preferably just enough to reorganize the material to the new, desired form. Mechanical properties improve after the treatment. Yield stress actually increases after the new heat treatment, while the yield stress generally decreases after a typical stress relief heat treatment. See, generally, R.J. Walter, *Plating & Surface Finishing*, October 1986, pp. 48-53; A.J. Dill, *Plating*, Nov. 1974, pp. 1001-1004; and A.W. Thompson and H.J. Saxton, *Metallurgical Transactions*, Vol. 4, June 1973, pp. 1599-1605.

Many materials are suitable for use with the new technique but one particularly preferred system includes nickel or a nickel/cobalt alloy, with small amounts of a sulfur-containing additive such as saccharin. This material is electroplated onto a substrate, then heat treated under moderate conditions.

A preferred method of deposition is electroplating, but other useful deposition processes include chemical vapor deposition (CVD), physical vapor deposition (PVD),

electrolytic or electroless aqueous solution plating of metals, and any process that causes deposition of materials through decomposition or reaction of gaseous, liquid or solid precursors.

5 The new technique of fabricating coatings with stable mechanical properties lends itself to fabricating resilient structures, structures that are critical in many applications such as microelectronic interconnections. In addition to the stable mechanical properties, many of the new coatings provide a structure with high electrical conductivity. Thus, by using this invention, a low-inductance, resilient interconnect can be fabricated.

10 In one particularly preferred embodiment, the coating is applied to a wire or ribbon to make a MicroSpring™ contact, such as that described in United States Patent No. 5,476,211, entitled "Method of Manufacturing Electrical Contacts, Using a Sacrificial Member". This technique has been developed in connection with work on such spring contacts, particularly for coating wires of some 1-2 mils (about 25-50 microns) thickness with a coating of some 1-2 mils (25-50 microns). In general, the technique is useful in thin film coatings of 200 or more  
15 Angstroms thick and for coatings with thick films of millimeter or even centimeter dimensions. One skilled in the art will appreciate that the teachings of this invention are applicable to a wide variety of structures.

In another particularly preferred embodiment, coating material is deposited on a shape to build up a useful contact or other structure with improved material properties. One  
20 preferred structure is the lithographic spring of Figure 3B, 3C. Other particularly preferred structures are the lithographic springs exemplified in Figures 9C and 10K.

Other deposition methods can be used. In particular, sputtering is useful for preparing an initial shaped deposit on a shape, then heat treating that initial shaped deposit to give a heat-treated, shaped deposit.

25 A "shape" for supporting a deposit by these deposition methods may take a variety of forms including: an elongate member such as a wire or a seed layer trace in an elongate configuration; a trench defined in a suitable, removable material; such a trench optionally including a material such as a platable seed layer; other shapes in or on a removable material; and such a shape optionally including a material such as a platable seed layer. One preferred  
30 shape is a wire skeleton. Another preferred shape is a structure defined in a masking material, with a seed layer in the structure. Another preferred shape is a structure defined by a patterned seed layer over a masking material where the shape of the patterned seed layer over the contours of the masking material influences where the first material is deposited. Yet

another preferred shape is a contoured masking material alone, where the first material is deposited according to a pattern such as an opening in a stencil or mask.

Although the inclusion of a dilute additive is useful in some exemplary embodiments, the important characteristic of a deposit is the character of the grain structure of the deposited metal. This disclosure teaches depositing a metal in an amorphous form, then heat treating to  
5 form a predominantly crystalline structure. With the right conditions, as taught in this disclosure, the resulting product has better material properties than the original deposit.

According to one preferred implementation, a resilient structure is fabricated by providing an elongate member, depositing a coating on the elongate member to give a coated  
10 elongate member, and heat treating the coated elongate member at a combination of time and temperature that gives a coating with improved material properties. The coating includes at least one metal and at least one additive.

According to another preferred implementation, a resilient structure is fabricated by providing an elongate member, depositing a coating on the elongate member to give a coated  
15 elongate member, and heat treating the coated elongate member at a combination of time and temperature that increases the yield strength of the coating. The coating includes at least one metal and at least one additive. Preferred metals include nickel and cobalt and preferred additives include saccharin and 2-butyne-1,4-diol.

According to another preferred implementation, a resilient structure is fabricated by providing an elongate member, depositing a coating as a metastable coating on the elongate  
20 member to give a coated elongate member, and heat treating the coated elongate member at a combination of time and temperature to initiate a transition in the metastable coating to give a stable coating. The coating includes at least one metal and at least one additive, the at least one additive capable of codepositing with the at least one metal.

According to another preferred implementation, a resilient structure is fabricated by providing an elongate member, depositing a coating as a nanocrystalline material on the  
25 elongate member to give a coated elongate member, and heat treating the coated elongate member at a combination of time and temperature to initiate a transition to give a coating that includes a crystalline material. The coating includes at least one metal and at least one additive  
30 capable of codepositing with the at least one metal.

According to one preferred embodiment, a resilient structure results from providing an elongate member, depositing a coating on the elongate member to give a coated elongate member, and heat treating the coated elongate member at a combination of time and



temperature that increases the yield strength of the coating. The coating includes at least one metal and at least one additive.

According to another preferred implementation, a structure with improved material properties is fabricated by providing a base part that includes a shape on which a first material  
5 can be deposited, depositing a first material on the shape to give an initial shaped deposit, and heat treating the initial shaped deposit at a combination of time and temperature to give a heat-treated, shaped deposit with improved material properties. The first material includes at least one metal. The shape may take a variety of forms, as described above.

According to another preferred implementation, a structure is fabricated by providing  
10 a base part that includes a shape on which a first material can be deposited, depositing a first material on the shape to give an initial shaped deposit, and heat treating the initial shaped deposit at a combination of time and temperature to give a heat-treated, shaped deposit with improved material properties. The first material includes at least one metal and at least one additive. Preferred metals include nickel and cobalt and preferred additives include saccharin  
15 and 2-butyne-1,4-diol. The shape may take a variety of forms, as described above.

According to another preferred implementation, a structure is fabricated by providing a base part that includes a shape on which a first material can be deposited, depositing a first material on the shape to give an initial shaped deposit which is a metastable shaped deposit, and heat treating the metastable shaped deposit at a combination of time and temperature to  
20 initiate a transition to give a heat-treated, shaped deposit which primarily is a stable shaped deposit and has selected material properties. The first material includes at least one metal. The shape may take a variety of forms, as described above.

According to another preferred implementation, a structure is fabricated by providing a base part that includes a shape on which a first material can be deposited, depositing the first  
25 material on the shape to give an initial shaped deposit which is a nanocrystalline deposit, and heat treating the nanocrystalline deposit at a combination of time and temperature to initiate a transition to give a heat-treated, shaped deposit which primarily is a crystalline deposit and has selected material properties. The first material includes at least one metal. The shape may take a variety of forms, as described above.

30 According to another preferred embodiment, a product with improved material properties results from providing a base part that includes a shape on which a first material can be deposited, depositing a first material on the shape to give an initial shaped deposit, and heat treating the initial shaped deposit at a combination of time and temperature to give a heat-

treated, shaped deposit with improved material properties. The first material includes at least one metal. The shape may take a variety of forms, as described above.

In another preferred embodiment, a structure has nearly maximal yield strength for such a structure, the structure including an elongate member and a coating on the elongate member. The coating is treated to give a resilient structure with a selected yield strength generally near the maximal yield strength for the composition of the coating. The coating that includes at least one metal.

In another preferred embodiment, a structure has nearly maximal yield strength for such a structure, the structure including an elongate member, and a coating on the elongate member, the coating treated to give a resilient structure with a coating includes a predominantly crystalline structure. The coating includes at least one metal.

In another preferred embodiment, a resilient contact structure has maximal yield strength for such a structure, the structure including a base part, with a body connected to the base part. The body includes in turn a first material, where the first material includes at least one metal, and where the body has been treated to give the body improved material properties.

In another preferred embodiment, a structure with predominantly crystalline grain structure includes a base part and a body connected to the base part. The body includes a first material, and the first material in turn includes at least one metal and at least one additive capable of codepositing with the at least one metal. The body is treated to give a structure with a selected yield strength, generally near the maximal yield strength for the composition of the first material in the form of the body.

This and other objects and advantages of the invention, as well as the details of an illustrative embodiment, will be more fully understood from the following specification and drawings.

#### **IV. Brief Description of the Drawings**

Figure 1 illustrates a flow chart of a method of manufacturing a coated wire according to a preferred embodiment of this invention.

Figure 2A illustrates a cross-sectional view of a skeleton attached to a base.

Figure 2B illustrates a cross-sectional view of an as-coated wire comprising a non-heat-treated coating covering the skeleton.

Figure 2C illustrates a cross-sectional view of a heat-treated coated wire comprising a heat-treated coating covering the skeleton according to a preferred embodiment of this invention.

5 Figure 3A illustrates a cross-sectional view of an alternate embodiment of an alternate plating substrate, here a spring contact element residing on a sacrificial substrate.

Figure 3B illustrates a perspective view of the spring contact element of Figure 3A, omitting a showing of the sacrificial substrate.

Figure 3C illustrates a cross-sectional view of another embodiment of a spring contact element mounted to another component.

10 Figure 4 illustrates a graph of a differential scanning calorimetry measurement of coated material.

Figure 5A illustrates a graph of an x-ray diffraction pattern from a sample of as-coated Ni-Co coating material.

15 Figure 5B illustrates a graph of an x-ray diffraction pattern from a sample of heat-treated Ni-Co coating material.

Figure 6 illustrates a graph of stress versus strain data for an as-coated wire and a heat-treated wire.

Figure 7 illustrates a graph of elastic modulus versus saccharin concentration for as-coated and heat-treated wires.

20 Figure 8 illustrates a graph of wire curvature before and after heat treatments at various times and temperatures.

Figure 9A is a side cross-sectional view of a technique for making a spring contact element.

Figure 9B is a side cross-sectional view of the spring contact element of Figure 9A.

25 Figure 9C is a perspective view of the spring contact element of Figure 9B.

Figure 10A is a side cross-sectional view of a step in a first exemplary embodiment of a process for making a contact structure.

Figure 10B is a side cross-sectional view of another step in the first exemplary embodiment of a process for making a contact structure.

30 Figure 10C is a top plan view of an interim product formed in the step shown in Figure 10B, according to the first exemplary embodiment of a process for making a contact structure.

Figure 10D is a side cross-sectional view of another step in the first exemplary embodiment of a process for making a contact structure.

Figure 10E is a side cross-sectional view of another step in the first exemplary embodiment of a process for making a contact structure.

5        Figure 10F is a top plan view of interim products formed in the step shown in Figure 10E, according to the first exemplary embodiment of a process for making a contact structure.

Figure 10G is a side cross-sectional view of another step in the first exemplary embodiment of a process for making a contact structure.

10        Figure 10H is an end cross-sectional view of the product formed by the step shown in Figure 10G, according to the first exemplary embodiment of a process for making a contact structure.

Figures 10I and 10J are perspective views of two of many possible configurations for the contact structure of the present invention, highlighting its funnel-like base end. Figure 10I illustrates a structure resulting from partially coating the sidewalls of an opening, as shown in  
15        Figures 10E and 10G generally. Figure 10J shows a structure resulting from fully coating the sidewalls of an opening, as shown in Figures 10E and 10G.

Figure 10K is a top plan view of an interim product formed in the step shown in Figure 10G, according to the first exemplary embodiment of a process for making a contact structure.

20        Figures 10L and 10M are side cross-sectional and perspective views, respectively of a completed contact structure formed on an electronic component, according to the first exemplary embodiment of a process for making a contact structure.

Figure 10N is a side cross-sectional view of a contact structure of Figures 10L and 10M with its tip end making contact with a contact pad of an electronic component.

25        Figure 10O is a side cross-sectional view of a contact structure of Figures 10L and 10M with its tip end soldered to a contact pad of an electronic component.

Figure 11 illustrates a top, plan view of one preferred shape for the contact structures of Figure 10K and related figures.

## 30    V.        Detailed Description of the Preferred Embodiment

This invention may start with an uncoated part of practically any shape. Generally speaking, the materials of this invention can be coated onto any suitable base or shape, then heat treated under moderate conditions as described to give a useful product. The base or

shape may or may not be retained, depending on the specific application. The deposition of coated material organizes into a desirable structure very early in the coating process, probably within the first few hundred Angstroms of material deposited, and coatings millimeters or even centimeters thick exhibit properties that, when heat treated, provide materials with the improved mechanical properties discussed herein.

When compared to other potential states for the material under study, specific improvements in mechanical properties of the heat treated material in a given structure may include increased (preferably approximately maximal) yield strength, increased (preferably approximately maximal) elastic modulus, and improved temperature stability. Other potential states include the material as coated (before heat treatment) and the material after extensive annealing (e.g. for stress relief).

One skilled in the art can follow the teachings of this invention to selectively control material properties. For example, the heat treatment can be selected to give minimal ductility, or can be selected to give selectively more ductility. In like manner, one can select heat treatment to give less than the maximal yield strength, or less than the maximal elastic modulus. One might, for example, wish to balance various material properties or accommodate other process constraints but still follow the teachings of this invention to make a material with properties improved over those of the material as coated without heat treatment.

One particularly preferred shape for a base is an elongate member such as a skeleton or a falsework. One preferred skeleton is a wire, which in turn may be secured to a substrate or base, or otherwise supported. Another preferred skeleton is a beam that is secured to but oriented to stand off from a substrate or base. It is particularly preferable to use an elongate member that can be formed into a spring shape. The elongate member does not need to be resilient, and in fact can be quite flexible to facilitate shaping into an arbitrary or desired form.

The basic material of this invention also can be deposited in other ways. For example, a desired shape can be defined on a substrate such as a silicon wafer by application of various materials as is well known in the art. Such materials can include photoresist for some applications. A shape can be defined by patterning, etching, and the like, then prepared for electroplating by depositing a thin seed layer, for instance a layer containing copper metal. The basic material can be plated onto that seed layer and heat treated as described below. Some or even all of the underlying materials may be susceptible to selective removal, leaving

the deposited material of this invention partially or completely free of the original substrate. The selective removal may be effected before or after the heat treating step, as desired.

Another preferred method of depositing material is sputtering. Material can be deposited in a suitable form that then can be heat treated to improve the material properties.

5        Figure 1 shows a flow chart of a method of manufacturing a coated wire according to one preferred embodiment of this invention.

First, a small wire skeleton 204 (see Figure 2A) is formed 102 on a base 202 (see Figure 2A). For example, the wire skeleton 204 may be made of gold wire, and the formation 102 may be done using a wirebonding machine. The base 202, for example, may  
10        comprise a semiconductor substrate. Many other bases 202 are, of course, possible, such as one comprising a ceramic, plastic, or metal substrate.

Second, a coating 206 (see Figure 2B) is deposited 104 onto the wire skeleton 204. The coating 206, for example, may be an approximately 50-50 (atomic percentage) nickel-cobalt (Ni-Co) alloy deposited using a plating bath that includes saccharin as an additive. The  
15        concentration of saccharin in the plating bath is discussed below in reference to Figure 8. The bath may be changed to vary the Ni/Co ratio, or to include a different additive instead of saccharin. Many variations of the plating bath will work.

In an alternative deposition method, no additives are included. A suitable material and suitable deposition conditions are selected to deposit the material in an amorphous form that is  
20        amenable to the heat treatment of this invention.

In general, coatings based on nickel, cobalt or iron (Ni, Co, Fe) are expected to give generally similar results. Preferred alloys include Ni-Co, Co-Mn, Ni-Mn, and various ternary alloys such as Ni-Co-Mn. Alternative coating materials include Ni-W-B, and Rh. Other possible coatings include Pd, Pd-Au, Pd-Co, W, W-Co, Ti-N, Cu, Cr, Ti, Ti-W, Al, Au, and  
25        Pt. Alternative additives include naphthalene-tri-sulfonic acid (NTSA), 2-butyne-1,4-diol, and thiourea. Other possible additives include NiCl, NiBr, as well as general Class 1 and Class 2 brighteners. All of these coating materials and additives are well known in the plating art.

Third, the as-coated wire 208 (see Figure 2B) is submitted to heat treatment 106 at a temperature above a transformation temperature of the coating 206 so that a heat-treated  
30        coated wire 212 (see Figure 2C) is formed. The heat treatment 106 of a Ni-Co alloy, for example, may be done at 350 °C for ten minutes or at 300 °C for sixty minutes. The time and temperature ranges at which the heat treatment 106 should occur (i.e., the heat treatment

window) are described below in reference to Figures 4 and 8. Of course for different alloy or additive systems, different heat treatment schedules may be required.

Figure 2A is a cross-sectional view of a wire skeleton 204 attached to a base 202. The skeleton 204 may be formed to be in various shapes, such as the one shown, in order to make  
5 useful resilient parts. One useful shape is that of a spring, or a springable shape. Different shapes will be useful depending on the application intended for the resilient part. Alternatively, the skeleton 204 may be a straight wire.

Figure 2B is a cross-sectional view of an as-coated wire 208 comprising a coating 206 over the wire 204. The coating 206 is of a thickness sufficient, in relation to the thickness of  
10 the skeleton 204, to significantly impact the mechanical properties of the as-coated wire 208. As described below in reference to Figures 5A, the as-coated coating 206 has an amorphous or nanocrystalline atomic configuration.

Figure 2C is a cross-sectional view of a heat-treated, coated wire 212 comprising a heat-treated coating 210 over the wire skeleton 204. The heat-treated, coated wire 212 is  
15 formed by heating 106 the as-coated wire 208 at a temperature greater than a transformation temperature of the non-heat-treated coating 206, preferably for a relatively short time. As described below in reference to Figures 5B, the heat-treated coating 210 has a crystalline or ordered atomic configuration. Furthermore, as demonstrated by the test results described below in reference to Figure 8, the heat-treated, coated wire 212 is resilient and, after being  
20 subject to simulated operating conditions, maintains its resiliency much better than the as-coated wire 208. Thus the thickness of coating 206 is sufficient to impart resiliency to the coated and heat treated structure.

A representative wire may have a diameter of about 1 to 1.5 mils (25 to 38 microns), with a coating thickness on the order of 1.5 mils (38 microns) for a total diameter of about 4  
25 mils (100 microns). Coating thicknesses as small as 200 to 500 Angstroms show the properties discussed here. Coatings can be relatively thick, certainly millimeters and probably on the order of centimeters or greater and still show the properties discussed here.

A useful coating can be deposited using electroplating. A typical plating bath and methodology is as follows. This illustrative, preferred implementation provides an alloy with  
30 improved hardness and mechanical properties with approximately a minimum of codeposited sulfur. A preferred grain refiner is sodium benzosulfimide ( $C_7H_5NO_3S$ ), also known as sodium saccharin. This and other grain refiners are well known to one skilled in the art. Although a sulfur-containing material is used in this preferred embodiment, this does not

appear to be an absolute requirement. For example, 2-butyne-1,4-diol has been shown to be effective in practicing the present invention. The additive or deposition conditions should promote formation of the desired coating structure, as discussed below.

Electroplating is well understood by one skilled in the art. When the conditions of the  
5 outlined electrolyte composition, electrodes, associated current densities, deposit thickness, and specified apparatus are employed, there is no evidence of Ni sulfide precipitation in grain boundaries at the heat treatment temperatures suggested in this disclosure. This absence of precipitation promotes prevention of grain boundary formation and embrittlement, which in turn can lead to premature product failure.

10 Successful product performance follows from high yield strength accompanied by suitable ductility. Experience has shown that "banded" (or lamellar) coating structures lead to favorable product performance. The addition of grain refining additives; such as naphthalene-tri-sulfonic acid (NTSA), NDSA, para-toluene sulfonamide or (preferably) sodium saccharin, will produce this "banding" to further enhance yield strength and desired spring back  
15 characteristics in the product. These additives in general should not alloy with but should co-deposit with the primary metal or metals being deposited. Thin deposits of certain alloys, including the codeposition of cobalt with nickel, may not show visible "banding" but nevertheless provide significant yield strength.

Alloy Deposition: Although the following solution make-up, control and operating  
20 conditions are specific to this preferred embodiment, one skilled in the art of alloy electroplating can produce comparable electrodeposits with superior properties for other applications. Recognized factors which influence the composition of an alloy in electrodeposition include electrolyte Ni/Co ratio in solution; current density, electrolyte agitation, pH, temperature; boric acid and total metal concentration.

25 Preferred Deposit Properties: As Plated (not heat treated)

Composition: 60%±2% Nickel by wt., 40% ±2% Cobalt

Hardness: ~550Knoop

Ultimate Strength:  $\sigma_{u265min}$  ksi (ksi = thousand psi)

Yield Strength:  $\sigma_y$  160 min ksi

30 Modulus: E22 ±2(Msi) (min. value) (Msi = million psi)

Elongation: 4.5%±. 5%



**Deposit Appearance:** The deposit was smooth and continuous, with high spectral reflectance. Conventional Hull Cell Panel tests showed this appearance over a wide range of plating current density.

Typical Solution Make-Up- One preferred implementation of this invention to produce a product with high resiliency is shown in Table 1 below. Plating is carried out in a conventional plating tank, such as a laminar flow polypropylene tank. Plating times and conditions are as needed to give satisfactory coatings.

**Table 1 - Typical Make-up**

	CHEMICAL	TYPICAL MAKE-UP
10	1) Ni Sulfamate	1) 100gm/L
	2) Boric Acid	2) 38gm/L
	3) Ni Bromide	3) 3-5ml/L (@18% conc)
	4) Co Sulfamate	4) 8.3gm/L (8.3 gm Co)
	5) Sodium Lauryl Sulfate	5) 25 dynes/cm
15	6) Na Saccharin	6) 100mg/L

In a typical process of this invention, these materials can be replaced in whole or in part by the alternative materials in Table 2, below.

**Table 2 - ALTERNATIVE MATERIALS OR COMBINATIONS**

	TYPICAL	ALTERNATIVE CHEMICALS
20	1) Ni Sulfamate	1a) Ni Sulfate      1b) Ni Acetate      1c) Ni Fluoborate
	1d) Ni Chloride	1e) Ni Sulfate-Chloride      1f) Ni Pyrophosphate
	2) Boric Acid	2) Citric Acid
	3) Ni Bromide	3a) Ni Chloride      3b) Magnesium Chloride
	4) Co Sulfamate	4a) Co Sulfate      4b) Co Chloride      4c) Co Fluoborate
25	5) Wetting Agent	5) A commercial wetter designed for plating applications
	6) Class 1 Brighteners	6a) Para-toluene sulfonamide      6b) Sodium naphthalene trisulfonic acid
		6c) Naphthalene disulfonic acid or a combination of 6a - 6c above.
30	7) Leveling Agents	7a) Coumarin      7b) Quinoline      7c) 2-Butyne-1,4-diol or a combination of Class 1 brighteners and Leveling agent.

In one preferred embodiment, the coating material is deposited on a wire that has been shaped in the form of a spring. After appropriate heating, the heat-treated spring substantially maintained its resiliency after being subject to simulated operating conditions. Such a

characteristic is very desirable for springs, especially for those used on a semiconductor device, semiconductor packaging, a semiconductor wafer, an electronic device for contacting one or more semiconductor devices, an electronic device for testing one or more semiconductor devices, a probe card, a probe, a connector, an interposer, or a socket. Such a characteristic is very desirable for springs whenever the maintenance of resiliency is important to maintaining pressure contacts. This same characteristic is also beneficial for purely mechanical components of any shape or geometry subject to loads at elevated temperatures for extended periods.

The preferred embodiment described herein is based on a coating over a wire, which may or may not be shaped to a desired form. The teachings of this invention are useful for coating other shapes as well. In particular, the object to be coated may be removed from the new coating before or after the heat treatment step. See, for example, co-pending United States Patent Application Serial No. 08/802,054 entitled "Microelectronic Contact Structure and Method of Making Same," commonly assigned with the present invention to FormFactor, Inc., now of Livermore, California. This and the corresponding PCT patent application, Serial Number 97/08271, filed 15 May 1997 and published 27 November 1997 as WO 97/44676, disclose forming a structure on a substrate, then removing the structure from the substrate to yield a free-standing part. See, for example, Figures 3A, 3B and 3C (Figures 3A, 3B and 4E, respectively, of the reference applications), which show a structure being formed on a substrate (Figure 3A), that same structure without the substrate (Figure 3B), and a structure attached to a different substrate (Figure 3C). Using the teachings of the present invention, one skilled in the art can coat the structures of Figures 3A, 3B and 3C at an appropriate time to prepare a coating as taught in the present disclosure. For example, spring contact element 460 (Figure 3C) might be joined to electronic component 470 then coated and heat treated. Alternatively, contact structure 300 (Figures 3A, 3B) might be coated and heat treated before removing sacrificial substrate 252.

Figures 3A and 3B illustrate another one of many possible embodiments for a contact structure 300 fabricated by the techniques described in the referenced applications. Sacrificial substrate 252 is used for preparing contact structure 300. A somewhat truncated-pyramidal joining feature (stud) 310 is fabricated as an attachment feature at the base portion 302 of the contact structure 300. The remaining portions of the contact structure 300 are a central main body portion 306, a contact end portion 304, and a feature 308, here a contact point. W1 and W2 are widths at the respective ends of the contact structure.

Figure 3C illustrates an alternate embodiment of the described invention wherein a spring contact element 460 is mounted to an electronic component 470 via a stud 472 extending from a surface of the electronic component 470. The base end 462 of the spring contact element 460 is suitably brazed to the stud 472.

5 In addition, one skilled in the art could select materials suitable as a substrate for coating, apply the teachings of this invention to apply such a coating, and subsequently remove the substrate to leave a product formed of the coating itself. In a particularly preferred embodiment, a contact structure such as 300 can be built up on a suitable substrate such that the coating forms the bulk of the material of contact structure 300. An alternative substrate  
10 might be a conductive layer over a material of a desired shape that in its own right might be readily removable. Such an implementation might start with a shape in wax, photoresist, or other material, then apply a thin conductive layer to promote plating, plate a coating as disclosed in this invention, then heat treat to give a product with the desired shape and properties. Two preferred embodiments of such a product are described in detail towards the  
15 end of this specification.

Figure 4 is a graph of a differential scanning calorimetry measurement on an as-coated coating similar to coating 206. The measurement starts with material as coated initially, without heating, and increases its temperature by 10°C per minute from room temperature (about 30°C) to 500°C while measuring heat flow.

20 The (inverse) peak 602 in the graph centered at about 266°C indicates that an exothermic transformation occurs in the material, particularly when the temperature is in the range indicated by the width of the peak 602. This exothermic transformation is deduced to be the transformation that changes the microstructure and atomic configuration from that of the as-coated coating 206 to that of the heat-treated coating 210. Since the peak 602 appears  
25 to begin above roughly 200 °C, a heat treatment 106 above about 200 °C should be able to cause such a transformation when Ni-Co alloy is used as the coating material. However, it is generally preferred to select a temperature near or somewhat above the peak temperature. In the illustrated example, the peak occurs at about 266°C and useful, preferred heat treatment conditions included 300° C for 60 minutes or 350°C for ten minutes. In general, one skilled  
30 in the art will recognize that a range of heating temperatures will give the desired effect. In general, a useful temperature range is within 0 and 150°C above the peak transition temperature and a particularly useful temperature range is within 0 and 100°C above the peak transition temperature.

A product that has been only partially transformed may be useful as well. One skilled in the art can follow the teachings of this invention to obtain a desired amount of transformation. In general, useful increases in material properties are seen if a substantial portion of the as-coated material undergoes a transformation to a more ordered state. One particularly preferred implementation involves heat treating a coated material at 300°C for fifteen minutes.

Figure 5A is a graph of an x-ray diffraction pattern from a sample of as-coated coating 206. The significant breadth of the two x-ray diffraction peaks shown in Figure 5 indicates a relatively small average grain size of about 16 nanometers in the material. (The average grain size was determined using the Debye-Scherrer formula which is well known in the art and gives a lower limit for the average grain size.) With an average grain size of 16 nanometers, the as-coated coating 206 may be characterized as a nanocrystalline or an amorphous material.

Figure 5B is a graph of an x-ray diffraction pattern from a sample of heat-treated coating 210 according to a preferred embodiment of this invention. In this case, the heat treatment 106 applied was 10 minutes at 330° C. The narrowness of the two peaks shown in Figure 5B indicates a relatively large average grain size of about 78 nanometers in the material. (Again, the Debye-Scherrer formula was used.) With an average grain size of 78 nanometers, the heat-treated coating 210 may be characterized as a crystalline or an ordered material.

Thus, as shown by Figures 5A and 5B, the coating material undergoes a transformation during heat treatment 106 from nanocrystalline or amorphous to crystalline or ordered.

Figure 6 is a graph of stress versus elongation (strain) data for an as-coated wire 208 and a heat-treated wire 212. These wires 208 and 212 tested here are straight, instead of being shaped in the form of a spring, so that the elongation (strain) measurement has meaning as a mechanical property of the material unrelated to the shape of the wires 208 and 212.

The data in Figure 6 shows that the heat-treated wire 212 has superior mechanical properties compared to the as-coated wire 208. The heat-treated curve 402 shows a higher yield stress (defined as the stress for a 0.2% strain) and higher elastic modulus compared to the as-coated curve 404. Thus the heat treated wire is elastic over a much larger range of applied stress. This indicates a higher resiliency of the heat treated springs, and appears to be due to a fundamental materials improvement. Since most mechanical components are designed to operate in the elastic regime (i.e. maintain their shape), a more resilient material

is more mechanically stable. Resilient material in the heat treated springs dramatically improves the stability of the mechanical properties at elevated temperatures under load.

When compared to other potential states for the material under study, specific improvements in mechanical properties of the heat treated material may include increased (preferably approximately maximal) yield strength, increased (preferably approximately maximal) elastic modulus, and improved temperature stability. Other potential states include the material as coated (before heat treatment) and the material after extensive annealing (e.g. for stress relief). The improved temperature stability is evidenced by increased resistance to deformation under load at elevated temperatures where the temperature may be somewhat above 25°C, including 85-100°C and even 300°C or more. This shows that the material is in a state more stable than the original material as coated.

Figure 7 is a graph of elastic modulus versus saccharin concentration for as-coated ("virgin" or "NHT" in Figure 7) wires 208 and heat-treated ("heat treated" or "HT" in Figure 7) wires 212. The graph shows that the elastic modulus for the heat-treated wires 212 is substantially greater than the elastic modulus for the as-coated wires 208 for all non-zero (in particular, 20mg/L or more) saccharin concentrations tested. When saccharin was used as an additive in the plating bath according to the formulation of Table 1, the heat-treated wires 212 typically had an elastic modulus of about 32 Msi while the as-coated wires 208 typically had an elastic modulus of about 24 Msi. Msi represents "mega" or million psi.

Fig. 8 is a graph of the wire curvature under 0.5 inch Mandrel tests on various wires coated with Ni-Co from a bath including saccharin. The Mandrel test consists of wrapping a straight plated wire around a mandrel of a given diameter to produce a fixed strain. (The mandrel material is selected to have the same thermal expansion coefficient as the wire to avoid additional stresses induced by differences in thermal expansion coefficient.) The wire is then attached to the mandrel at both ends to maintain the strain. The mandrel-wire assembly can then be exposed to any time/temperature combination. This test is a convenient way to test material properties under load at elevated temperature as a function of time, an extremely useful means of mimicking different operating conditions. The amount of plastic deformation that occurs for a given test condition is reflected by changes in the resulting wire curvature, where curvature is defined as:

$$curvature = 100 * \left[ \frac{radius_{outer-edge-of-wire}}{radius_{wire-center}} - 1 \right]$$

Fig. 8 shows the effect of different heat treatment temperatures on wire curvature. A set of as-plated wires had their curvatures measured at room temperature. They were then subjected to a 7 minute heat treatment at different temperatures, cooled to room temperature, and again measured for curvature. They were subjected to a two minute Mandrel test at room temperature, and again measured for curvature. They were then subjected to a 13 hour Mandrel test at 85°C, cooled to room temperature, and again measured for curvature. Finally, they were subjected to an additional 24 hour Mandrel test at 85°C (for a total duration of 37 hours at 85°C), cooled to room temperature, and measured for curvature. As seen in Fig. 8, the plastic deformation associated with mechanical loading for two minutes at room temperature are nominally the same for the wires heat treated at various temperatures. However, when mechanically loaded at elevated temperatures, the a wire heat treated at higher temperatures ( $\leq 400^{\circ}\text{C}$ ) shows smaller plastic deformation. This is another indication of the improved mechanical properties after heat treatment. The mechanical properties are essentially constant for coated wires heat treated at  $T \geq 350^{\circ}\text{C}$ , consistent with the results of Figure 4 (see corresponding text, above).

The description above has discussed in detail certain Ni and Ni/Co systems with a variety of potential additives, particularly saccharin. However, the general principles can be used to plate a wide variety of systems, with a variety of additives, then heat treated under moderate conditions to give a product with the desired properties. Under certain deposition conditions, no additives are needed.

Potential metal systems are listed in detail above. Additives used to date for the most part include sulfur, but 2-butyne-1,4-diol has been used to give the desired transformation. In one preferred embodiment, a bath concentration of more than or equal to about 20 mg/L saccharin was useful. In another preferred embodiment, a bath concentration of more than or equal to about 5 mg/L 2-butyne-1,4-diol was useful.

Although the physical properties are not fully understood, the general theory is that the material as deposited has a non-equilibrium, nanocrystalline structure. If present, the additive is in relatively low concentration and is dispersed throughout the coating as deposited. If the coated material is heated for some time, the crystal structure reorganizes to give larger crystals. The additive diffuses and the primary metal organizes in a way that is affected by the additive molecules, perhaps as a crystal directly incorporating the additive, perhaps as grains that accommodate the additive molecules, or perhaps in some as-yet-not-understood structure. Further heat treatment leads to a different organization where the base material organizes into

large structures, excluding the additive and/or the additive collects as a precipitate, segregated from the primary metal. This is the structure that results after traditional annealing (which also generally does not include the additives of the present invention).

To ascertain a useful amount of additive and useful heat treatment conditions is not  
5 difficult. While predictions can be made by studying the diffusion rate of a selected additive in the base metal system, a few experiments will outline the primary parameters very quickly. The temperature range where the intermediate heat treatment is most likely to occur can be selected by coating the desired metal system onto a suitable substrate, then performing differential scanning calorimetry (DSC) as described above. The transition temperature is  
10 readily identifiable, and the peak of that transition temperature is a good starting point for subsequent experiments. For this initial experiment, the amount of additive is not very important as the additive has little or no effect on this transition temperature.

A useful amount of additive can be identified by preparing a test product using varying  
15 amounts of additive, for example, 2.5%, 1%, 0.1% and 0.01% on a molar basis, then heat treatment for a brief time, for example 5, 10 or 20 minutes, at or near the temperature identified above. The tensile strength of the resulting heat treated product will show which conditions give the desired mechanical properties. A particularly useful test structure is a traditional dog-bone suitable for testing in a traditional tensile strength tester. Alternatively, a coated wire will provide useful tensile information. With initial information about effective  
20 amounts of additive, different time and temperature conditions can be evaluated to quickly settle on a useful set of conditions.

For a given amount of additive, upon heat treatment in varying amounts, the yield stress generally will increase to a maximum, but then decrease. In general, the maximum yield stress will be found at a relatively narrow band of heat treatment conditions (balancing  
25 time and temperature). This point may not give the desired ductility properties. In general, heat treatment beyond the point of this maximum yield stress condition will increase ductility, and a modest increase in heat treatment will give a part which has close to the maximal yield stress together with a desired amount of ductility. Continued heat treatment ultimately will decrease the yield stress, generally decreasing the resiliency of the treated coating. This  
30 continued heat treatment in general will increase ductility. It is well within the skill in the art to identify heat treatment conditions to impart a desired degree of yield stress and a desired degree of ductility in a given coating system, subject to the limitations of that coating system.

One skilled in the art can use the principles of experimental design to identify key components and values with relative ease. This field has been the subject of considerable academic interest. For example, the library at the University of California, Berkeley, listed some 287 references for experimental design in the electronic card catalog in September 1997.

- 5 See [www.lib.berkeley.edu](http://www.lib.berkeley.edu), or, particularly [www.lib.berkeley.edu/ENG/about.html](http://www.lib.berkeley.edu/ENG/about.html). In particular, the study of factorial experimental designs or fractional factorials may be useful. The Berkeley collection lists some fourteen relevant references. Of particular interest might be the basic references "Statistics For Experimenters, An Introduction to Design, Data Analysis, and Model Building," George E.P. Box, Wiley, New York (1978) and "Empirical Model-  
10 Building and Response Surfaces," George E.P. Box and Norman R. Draper, Wiley, New York (1987).

#### Exemplary Embodiment of a Resilient Contact Structure

- Representative embodiments of base structures suitable for heat treatment have been described above in connection with Figures 2A-2C and Figures 3A-3C. The present method of  
15 heat treatment is useful with other resilient contact shapes, in particular shapes that are the subject of two other United States (and corresponding PCT and other foreign) applications. It may be helpful to consider these examples in some detail.

- For purposes of practicing the present invention, the materials listed above in connection with Figure 2A-2C and 3A-3C are particularly preferred when making the resilient  
20 contact structures described in these exemplary embodiments.

- Commonly-owned, copending U.S. Patent Application No. 08/852,152, filed 6 May 1997, entitled "Microelectronic Spring Contact Elements", discloses a useful product and method of making elements similar to those discussed above. The corresponding PCT  
25 application was published 20 November 1997 as WO 97/43654. The materials discussed above may be used in the process to make the products of application 08/852,152, and may further be heat treated as disclosed herein to make a superior contact element.

- Generally, a number of masking layers having openings formed therein are aligned and "seeded" with a layer of conductive material. A mass of conductive material can then be formed (or deposited) in the seeded opening(s), such as by electroplating (or CVD, sputtering,  
30 electroless plating, etc.). After the masking layers are removed, the mass can function as a free-standing resilient contact structure. Such a structure may extend not only vertically above the surface of the component, but also laterally from the location of mounting. In this manner, the contact structure is readily engineered to be compliant in both the Z-axis as well as in the



x-y plane (parallel to the surface of the component). This is described in greater detail now with respect to Figures 9A-9C (Figures 1A-1C of the WO 97/43654 disclosure).

Remember that the contact element is resilient, so "compliance" (accommodation of deformation) varies with the amount of displacement from a resting position and the spring constant (restoring force) of the contact element. Small displacements are opposed by relatively small restoring forces but greater displacements are opposed by greater restoring forces.

Figure 9A illustrates an exemplary technique for fabricating one of a plurality of free-standing resilient (spring) contact elements on a substrate 902. The substrate 902 may be an active electronic component, including a semiconductor device, particularly including semiconductor devices resident on a semiconductor wafer (not shown).

The substrate 902 has a plurality (one of many shown) of areas 912 on its surface where a spring contact element can be fabricated. In a preferred embodiment where substrate 902 is an electronic component such as a semiconductor device, area 912 is a terminal (such as a bond pad) of the electronic component. In another preferred embodiment, with rerouting, a primary terminal is connected to an electrically conducting material such as a metal trace, and connected to a remote terminal at some different location on the electronic component. Various types of rerouting are understood in the art. With regard to the general technology of the present invention, a preliminary discussion of rerouting can be found in PCT application PCT/US95/14885 published as WO 96/15459 on 23 May 1996.

Such rerouting is useful for remapping a set of terminals from a first array to a second array. A useful remapping is to reroute a peripheral bond pad array to an area array. Another useful remapping is to reroute a lead-on-center bond pad array to an area array. Rerouting in general can provide great flexibility in positioning electrical contacts. The process described below can be used to build a contact element on a primary terminal but equally well to build a contact element on a remote terminal.

Generally, the technique to make a product 900 involves applying a number (three shown) of patterned masking layers 904, 906 and 908 having openings onto the surface of the substrate. The layers are patterned to have openings (as shown) aligned with the areas 912, and the openings are sized and shaped so that an opening in a one layer (e.g., 908, 906) extends further from the area 912 than an opening in an underlying layer (e.g., 906, 904, respectively). In other words, the first layer 904 has an opening directly over the area 912. A portion of the opening in the second layer 906 is aligned over at least a portion of the

opening in the first layer 904 and, conversely, a portion of the first layer 904 extends under a portion of the opening in the second layer 906. Similarly, a portion of the opening in the third layer 908 is aligned over at least a portion of the opening in the second layer 906 and, conversely, a portion of the second layer 906 extends under a portion of the opening in the third layer 908. The bottom portion of a given overall opening is directly over the selected area 912 and its top portion is elevated and laterally offset from its bottom portion. As will be discussed in greater detail hereinbelow, a conductive metallic material is deposited into the openings, and the masking layers are removed, resulting in a free-standing contact structure having been fabricated directly upon the substrate with its base end secured to the substrate 902 at the area 912 and its free end extending both above the surface of the substrate and laterally-displaced from the area 912.

If required, such as for electroplating, a very thin (e.g., 4500 Ångstrom) "seed" layer of conductive material 914 such as titanium/tungsten (TiW) may be deposited into the openings. Then, a mass of conductive metallic material (e.g., nickel) 920 can be deposited by electroplating into the openings. A deposit of about 0.1 to 10 mils, preferably about 1 to 10 mils, and more preferably about 1 to 3 mils of metal is particularly preferred. A particularly preferred metal is nickel.

Figures 9B and 9C illustrate a resulting spring contact element 920 having its base end 922 adjacent the area 912, and its free-end (tip) 924 elevated in the z-axis above the surface of the substrate 902 as well as laterally offset in the x-axis and y-axis from the base end 922.

As best viewed in Figure 9C, the contact element 920 will react to pressure applied in the z-axis at its tip end 924, as indicated by the arrow 924, such as would result from making a temporary pressure electrical connection with a terminal (not shown) of another electronic component (not shown). Compliance in the z-axis ensures that contact force (pressure) will be maintained, and also accommodates non-planarities (if any) between terminals (not shown) on a second, mating electronic component (not shown). Such temporary electrical connections are useful for making temporary or even long-term connections to the electronic component 902.

The tip end 924 is also free to move compliantly in the x- and y- directions, as indicated by the arrows 936 and 934, respectively. This would be important in the context of joining (by soldering, or brazing, or with a conductive adhesive) the tip end 924 to a terminal (not shown) of another electronic component (not shown) which has a different coefficient of thermal expansion than the substrate (component) 902. Such permanent electrical connections

are useful for assemblies of electronic components, such as a plurality of memory chips (each of which is represented by the substrate 902) to another electronic component such as an interconnection substrate such as a printed circuit board ("PCB"; not shown).

By suitable choice of material and geometry, these fabricated masses 920 can function  
5 as free-standing resilient contact structures that have been fabricated with very precise dimensions and very precise spacings from one another. For example, tens of thousands of such spring contact elements (920) are readily precisely fabricated on a corresponding number of terminals on semiconductor devices that are resident on a semiconductor wafer (not shown).

10 Viewed from a very general perspective, the patterned openings in the masking material constitute a shape into which material can be deposited and later heat treated. For electroplating purposes, it is preferred to deposit the seed layer as described above. This seed layer also can be considered a shape upon which material can be deposited and later heat treated. Material could be deposited directly into the openings by some other method, such as  
15 sputtering through a mask or other deposition method, much as described for the seed layer, but using material suitable for subsequent heat treatment, and depositing the material to a thickness useful for making a useful structure. Here again, the openings in the masking material form a shape that defines to a significant extent the shape of the final, resulting structure.

#### 20 Second Exemplary Embodiment of a Resilient Contact Structure

The process described hereinabove with respect to Figures 9A-9C utilizes three layers (904, 906, 908) of masking material which must be patterned and applied upon one another, resulting in a multi-level trench into which the material 920 can be deposited.

A comparable contact structure can be fabricated with fewer layers of masking  
25 material (e.g. photoresist). As before, this is particularly useful for microelectronic applications. Figures 10A-10L illustrate an embodiment of the technique of the present invention. These figures and accompanying description are taken from copending, commonly assigned US Patent Application Serial No. 09/032,473, filed 26 February 1998, entitled "Lithographically Defined Microelectronic Contact Structures," also found in the  
30 corresponding PCT Application Number PCT/US98/09999, filed 14 May 1998.

Figure 10A shows an exemplary electronic component upon which a plurality of contact structures can be fabricated. In the main hereinafter, the fabrication of a single contact structure (1060) will be described as exemplary of fabricating a plurality of such

contact structures, preferably all at the same time on the same electronic component or base. Typically, each of the contact structures fabricated on a single component will be substantially identical to one another (i.e., dimensions, shape, etc.), but using techniques known in the art the dimensions and shape of each contact structure can individually be controlled and  
5 determined by the designer for given application requirements.

In this preferred implementation, the electronic component is a semiconductor device comprising a silicon substrate 1002, a passivation layer 1004 (e.g., polyimide, about 4  $\mu$ m thick) disposed on the surface of the silicon substrate 1002, and a plurality (one of many shown) of openings 1006 extending through the passivation layer 1004 to a metallic contact  
10 pad 1008. Typically, there is a plurality of such contact pads on an electronic component. In the prior art, in a complete assembly, each contact pad typically is connected (e.g., as with a bond wire) to a corresponding contact pad on another electronic component (not shown), such as a lead frame and ultimately into a thin small-outline package (TSOP).

Here, as shown in Figure 10A, in a first step of the process, a conductive layer 1010 is  
15 deposited. The conductive layer 1010 is, for example, titanium-tungsten (Ti-W) which may be deposited by sputtering to a thickness of about 3000-6000 Å (Angstroms), such as to a thickness of about 4500Å. The conductive layer 1010 substantially conformably and contiguously covers the surface of the passivation layer 1004, the sidewalls of the opening 1006 and the exposed surface (within the opening 1006) of the metallic contact pad 1008. The  
20 conductive layer 1010 is preferably electrically conductive and, if deposited as a continuous "blanket" layer, will electrically short together all of the contact pads (1008) of the electronic component. As will become evident from the description that follows, this shorting feature of the conductive layer 1010 can advantageously be employed to establish an appropriate potential for an electrolytic process (e.g., electroplating) for fabricating contact structures on  
25 the electronic component.

In one preferred embodiment, the conductive layer 1010 is patterned rather than continuous and can be deposited as multiple, non-contiguous regions. In another preferred embodiment, the conductive layer 1010 covers the exposed surface of terminal 1008. In an alternative embodiment, the conductive layer 1010 covers only a portion of terminal 1008. In  
30 another alternative embodiment, conductive layer 1010 does not cover terminal 1008 at all but is sufficiently close to terminal 1008 such that when seed layer 1050 is applied, it makes contact with conductive layer 1010.

In one preferred embodiment, a second conductive layer of another material (such as gold) can be deposited and patterned onto the conductive layer 1010. This can be used, for example, to effect local interconnections and rerouting of signals from the contact pad 1008 to the contact structure (1060). In general, a dual layer may be preferred for many applications.

5 Selection of suitable materials is within the skill in the art.

In a preferred embodiment, the contact pad (1008) is on the surface of the substrate (1002) or in the surface of the substrate (yet exposed) itself, without there being a passivation layer (1004), although a passivation layer is commonly present on semiconductor devices. Prior to depositing the conductive layer 1010, the passivation layer 1004 (if there is one  
10 present) may optionally first be "roughed up" to enhance adhesion of the conductive layer 1010 to the passivation layer 1004. This can simply be accomplished by exposing the electronic component to an oxygen (O<sub>2</sub>) plasma with suitable parameters (that may be determined readily by one skilled in the art) to obtain a desired surface texture on the passivation layer. Choice of materials will also affect adhesion of the seed layer to the  
15 passivation layer. Titanium-tungsten (Ti-W) or copper, for example, is known to adhere well to polyimide.

As shown in Figure 10B, in a next step of the process, a layer of masking material (e.g., photoresist) 1020 is deposited onto the surface of the component 1002 (i.e., onto the conductive layer 1010) and is patterned (e.g., using conventional photolithographic  
20 techniques) to include an opening 1022 extending completely through the masking layer 1020. The opening 1022 may be located either at a position which is over (as shown) the opening 1006 in the passivation layer 1004, or may be located at a position which is remote from the opening 1006 and, consequently, remote from the contact pad 1008.

As described above, and as described in greater detail in the reference 09/032,473  
25 disclosure, by locating the openings 1022 at positions remote from the contact pads 1008, a plurality of contact structures can be fabricated on the electronic component with a layout that differs from that of the contact pads of the electronic component. One particularly preferred configuration is to position openings 1022 so that contact structures built thereon will have tips in an area array comparable to a typical ball grid array. The openings can be connected  
30 to contact pads on the electronic component arranged, for example, as peripheral pads. It may be advantageous to make the contact structures substantially identical without displacement from the contact pads. In this instance, it is useful to locate openings 1022 in an area array corresponding to the array of the tips of the ultimate contact structures.

Each opening 1022 preferably has a larger area than the area of opening 1006 over the contact pad 1008. For example, a square contact pad 1008 measuring 4 mils x 4 mils (i.e., 100  $\mu\text{m}$  x 100  $\mu\text{m}$ ) would have an exposed area of 10,000  $\mu\text{m}^2$ , and a square opening 1022 measuring 200  $\mu\text{m}$  x 200  $\mu\text{m}$  would have an area of 40,000 (four times the exposed area of the contact pad 1008). A circular opening 1022 having a diameter of 200  $\mu\text{m}$  would have an area of 31,400  $\mu\text{m}^2$  (approximately three times the exposed area of the contact pad 1008). In general, it is preferred that the opening exposes an area of the terminal and/or substrate of between about 10,000 and about 40,000  $\mu\text{m}^2$ , most preferably in excess of about 30,000  $\mu\text{m}^2$ . Although not a key feature of the invention, as a general proposition, the footprint (base end area) of the contact structure should provide sufficient area for the mechanical securement (adhesion) of the contact structure to the electronic component.

Regarding the openings 1022, it is preferred that they be tapered, and that the dimensions at the bottom of a tapered opening be on the order of 200  $\mu\text{m}$  x 200  $\mu\text{m}$  for a square opening, or 200  $\mu\text{m}$  diameter for a circular opening. In applications that are space-constrained, and these dimensions are not possible, the available space can be used. For example, when dealing with an electronic component having 100  $\mu\text{m}$  x 100  $\mu\text{m}$  pads on 125  $\mu\text{m}$  centers, the openings 1022 can have dimensions on the order of 105  $\mu\text{m}$  x 105  $\mu\text{m}$ , 110  $\mu\text{m}$  x 110  $\mu\text{m}$ , or the like, including non-square dimensions. Alternatively, in applications that are space-constrained, the bases of the contact structures can be remotely located from the pads to which they are electrically connected and have larger (e.g., 200  $\mu\text{m}$ ) preferred dimensions. The tapered (sloped) region of the opening 1022 is designated by the reference numeral 1023 in Figure 10B.

The masking layer 1020 is preferably deposited to a thickness of at least about 50  $\mu\text{m}$ , or alternatively to a thickness of at least about 100  $\mu\text{m}$ , at least about 150  $\mu\text{m}$ , and at least about 200  $\mu\text{m}$ . The masking layer 1020 can be deposited as multiple layers. It is the overall thickness of the masking layer 1020 that will determine primarily the distance that the main body portion of the contact structure is spaced away from the surface of the electronic component. Note the offset distance "d2" of the main body portion 1066 from the base portion 1062 of the spring contact element 1060 shown in Figure 10L.

Preferably, the sidewalls (edgewalls) of the openings 1022 are tapered so that the opening may be larger at the surface of the masking layer 1020 than at the conductive layer 1010. This is referred to as a "positive" taper. No taper would result in steep sidewalls

having an angle of 90° (ninety degrees). Preferably, the sidewalls of the openings have an average taper angle of about 60-75°. This may readily be accomplished using photoresist as the material for the masking layer 1020, and baking the photoresist and re-flowing it. One having ordinary skill in the art to which the present invention most nearly pertains will readily understand how to control the sidewall taper in light of the description presented in the reference 09/032,473 disclosure. The tapered opening can be formed in any suitable manner and may, in fact, be stepped like an inverted, stepped, truncated pyramid. Controlling the shape of the opening (1022) in the masking layer (1020) is discussed in greater detail in the 09/032,473 disclosure.

Figure 10C is a top plan view of the electronic component of Figure 10B, showing two openings 1022a and 1022b in the masking layer 1020, each opening associated with a one of two contact pads 1008a and 1008b (shown in dashed lines), respectively. The tapered regions of the openings 1022a and 1022b are designated by the reference numerals 1023a and 1023b, respectively, in this figure.

As shown in Figure 10D, in a next step of the process, for each of selected ones of the plurality of openings 1022, a protruding feature 1030 may be deposited onto the surface of the masking layer 1020 with its center at a distance "L" from the a center of the opening 1022. As will become evident, this feature 1030 will define the contact (tip) end (1064) of a resulting contact structure (1060) being fabricated on the electronic component, and the distance "L" represents the straight-line distance between the base (1062) and tip (1064) ends of the contact structure (1060) being fabricated on the electronic component. The protruding feature 1030 can be a "dot" or "dollop" of material, for example exhibiting a squashed hemispherical shape. Useful and preferred protruding features include a small quantity of epoxy, photoresist, or the like which may suitably be applied through a stencil or by using conventional screen printing techniques. The protruding feature 1030 may also be of a conductive material. Suitable dimensions for a protruding feature 1030 in the form of a squashed hemispherical dot are about 5-15 mils (125-375  $\mu\text{m}$ ) in diameter and about 2 mils (50  $\mu\text{m}$ ) in height. In one preferred embodiment the protruding feature can be skinnier (e.g., less than about 5 mils wide), while in another embodiment it can be wider (e.g., greater than about 15 mils wide). For typical uses, it is preferred that its height be in the range of about 2 - 7.5 mils.

As described in greater detail in the 09/032,473 disclosure, other shapes are useful for the protruding feature - more broadly, a variety of shapes in which the resulting tip end

(1064) of the contact structure (1060) may be fabricated, including pyramidal, conical or hemispherical, and truncated versions of pyramidal, conical or hemispherical, and cruciform, rings and the like.

One having ordinary skill in the art will readily understand how to apply and control the shape of the protruding features 1030 in light of the description presented herein. For example, using photoresist and a stencil (not shown) to create the protruding features 1030, with the stencil in place, the photoresist can be soft-baked to release the protruding feature from the stencil then, after removing the stencil, hard-baked.

The distance "L", between the base end (1062) and tip end (1064) of the resulting microelectronic spring contact structure may be, for example, in the range of about 10-1000 mils, preferably in the range of about 10-50 mils.

As shown in Figure 10E, in a next step of the process, a stencil (shadow mask) 1040 may be disposed over the surface of the masking layer 1020. The stencil 1040 has a plurality (one of many shown) of openings 1042. As illustrated, an opening 1042 extends from opening 1022 to a corresponding protruding feature 1030. The stencil 1040 may suitably be a thin (e.g., about 2 mil (50  $\mu\text{m}$ ) thick) foil of stainless steel which may be punched or etched to have openings 1042. Stencil 1040 can be of any suitable material having any suitable thickness which will permit a seed layer 1050 to be deposited onto the masking material 1020 in a pattern of conductive traces corresponding to the shapes of the openings 1042.

With the stencil 1040 in place on the surface of the masking layer 1020, a "seed" layer 1050 is deposited, such as by sputtering, onto the exposed surfaces of the masking layer 1020 and protruding features 1030. The seed layer 1050 is deposited within the exposed portions of opening 1022 and onto the surface of the conductive layer 1010 within opening 1022. The seed layer 1050 has a sloped region 1053 where it is deposited on the sloped region 1023 of the opening 1022 in the masking material 1020.

An alternative embodiment of the seed layer such 1050 is deposited by screen printing a conductive ink. Suitable conductive ink includes palladium ink or graphite ink. Such materials and processes are used in the manufacture of printed circuit boards and are well known in the art.

The seed layer can be considered a shape upon which material is later deposited to form a structure of this invention. From another perspective, the patterned seed layer is an elongate component that can be coated to form a structure of this invention. From still another perspective, the surface of masking material 1020 and the opening 1022 is a shape suitable for



direct deposition by a process such as sputtering of a bulk material that is suitable for the heat treating of this invention. Such a deposition can be patterned by depositing through a suitable mask.

5 The seed layer 1050 may be deposited as a pattern of a plurality of "traces", each of which is a physical realization of the pattern of openings 1042 in the overlying stencil 1040. The seed layer 1050, as patterned, serves as a precursor for a contact structure to be fabricated on the electronic component. For example, in an electroplating process, the conductive traces of the seed layer 1050 will each serve as an electroform whereupon the substance (mass) of the contact structure (1060) can be fabricated.

10 The selection of masking material 1020 and process for deposition of seed layer 1050 need to be considered together. The masking material needs to be stable in the environment of the deposition method. For example, a typical positive photoresist material contains some solvent and may outgas under high vacuum conditions. It is preferable in this instance to modify the material, for example by baking or exposure to light in order to cross-link or  
15 otherwise rigidify the masking material. Polyimide is a useful masking material and will tolerate a sputtering environment without significant degradation. Deposition also can be by means of chemical vapor deposition (CVD) or e-beam processes. These require less vacuum than does sputtering. For these, traditional Novolac photoresist resins can be used, perhaps with some moderate cross-linking. Another consideration is that any modification to the  
20 masking material to make it stable under vacuum may make it more difficult to remove later in the process. A suitable material and process can be selected by one skilled in the art.

One particularly preferred process is to use Novolac photoresist, patterned as described above, then partially cross-linked by heating. Deposition of seed layer 1050 is performed using CVD.

25 Figure 10F illustrates the result of the steps described in Figure 10E in top view, and shows two openings 1042a and 1042b in a stencil 1040, each opening 1042a and 1042b extending from over an associated one of two contact pads 1008a and 1008b (shown in dashed lines) to a selected one of two protruding features 1030a and 1030b (shown in dashed lines), respectively.

30 Figure 10F also illustrates two patterned traces 1050a and 1050b of the seed layer having been deposited through the openings 1042a and 1042b, respectively, in the stencil 1040. The traces 1050a and 1050b are illustrated with cross-hatching, for illustrative clarity,

but it should clearly be understood that this cross-hatching does not indicate a cross-section in this figure.

Each of the traces 1050a and 1050b illustrated in Figure 10F has a base end 1052a and 1052b, a tip end 1054a and 1054b, and a central body portion 1056a and 1056b, respectively, corresponding to the base ends (1062), tip ends (1064) and main body portions (1066), respectively, of contact structures (1060) that will be built up onto the conductive traces 1050a and 1050b. The sloped regions 1053a and 1053b of the traces 1050a and 1050b, respectively, are illustrated in this figure.

Figure 10G illustrates a next step of the process, wherein the shadow mask 1040 has been removed and a plurality (one of many shown) of contact structures 1060 are built up, such as by plating (e.g., electroplating), as a mass of conductive material upon the plurality (one of many shown) of traces 1030. Each contact structure 1060 has a base end portion 1062 (compare 302 of Figure 3B), a tip end portion 1064 (compare 304 of Figure 3B), and a main body portion 1066 (compare 306 of Figure 3B) extending between the base end portion 1062 and the tip end portion 1064. As illustrated, the contact structure 1060 has a sloped region 1063 between its base end 1062 and its main body portion 1066, the sloped region 1063 being built on the sloped region 1053 of the seed layer 1050 which, in turn, is built on the sloped region 1023 of the opening 1022 in the masking material 1020.

Figure 10H is a cross-sectional view of the electronic component of Figure 10H, taken on a line 10H-10H, illustrating the profile (transverse cross-section) of a contact structure (1060) made according to one preferred implementation of the invention. The profile is roughly semicircular or mushroom-shaped. This section, taken through the main body portion 1066 is representative of the profile of the contact structure throughout its entire length. This structure is a result of electroplating on an exposed seed layer that is in large part approximately planar.

Referring to Figure 10G (see also Figure 10L), the overall height "H" of the resulting contact structure 1060, in other words the height of its tip end 1064 away from the surface of the substrate 1002, is preferably at least about 4.0 mils, and may be about 8.0 mils or greater.

Referring to Figure 10H, the thickness "t" of the main body portion 1066 - in other words, of the mass of conductive material on the trace 1050 - preferably is at least about 0.5 mils and may be about 1.5 mils or greater.

Referring to Figure 10H, the width "w" of the main body portion 1066 - in other words, of the mass of conductive material on the trace 1050 - preferably is at least about 0.5

mils and may be about 4.0 mils or greater. In one preferred embodiment, the width is approximately constant along the main body portion 1066. In a particularly preferred embodiment, the main body portion is tapered in width, for example, from wider near the base end 1064 to narrower near the tip end 1066 of the main body portion 1066.

5           As mentioned hereinabove, the length "L", between the base end (1062) and tip end (1064) of the resulting microelectronic contact structure (1060) is suitably at least about 10 mils and may be as long as about 50 mils or greater, even much greater.

          Viewed from a very general perspective, the patterned openings in the masking material constitute a shape into which material can be deposited and later heat treated. For  
10   electroplating purposes, it is preferred to deposit the seed layer as described above. This seed layer also can be considered a shape upon which material can be deposited and later heat treated. Material could be deposited directly into the openings by some other method, such as sputtering through a mask or other deposition method, much as described for the seed layer, but using material suitable for subsequent heat treatment, and depositing the material to a  
15   thickness useful for making a useful structure. Here again, the openings in the masking material form a shape that defines to a significant extent the shape of the final, resulting structure.

          The general requirements for the design of a spring shape are generally known in the art. Details such as dimensions, bending moment, shape to allow flexibility in various  
20   dimensions, and the like can be selected by the designer and implemented according to the teachings of this invention. One particularly preferred shape approximates a circular section with a tapered inner and outer radius of curvature. Such a shape is illustrated in Figure 11 (Figure 7 of the reference 09/032,473 disclosure).

          Figures 10I and 10J are perspective views of two of many possible configurations for  
25   the contact structure 1060 of Figure 10G, disassociated from the component 1000, for illustrative clarity. These figures illustrate two important variations that can be selected using this invention. In Figure 10I, the contact structure has a square base end 1062. In Figure 10J, the contact structure has a round (circular) base end 1062. In both of these figures, the funnel shape of the base end in the sloped region 1063 is readily appreciated, said shape having been  
30   imparted to the base end by the sloping sidewalls (1023) of the opening 1022 in the masking layer 1020. In Figure 10J, the sloped region 1063 of the base end 1062 is completely covered (360°), and a small "lip" extends around the entire base end. This complete funnel shape is readily obtained using a stencil 1040 that allows deposition of a seed layer along all of the side

walls and a portion of the surface of masking layer 1020. Figure 10I shows the result of depositing a seed layer on only a portion of the sidewalls of opening 1022. This is readily obtained using a stencil that covers a portion of opening 1022, as illustrated in Figure 10E. More or less of the sidewalls can be covered according to the mask and deposition conditions selected. This may include only a portion of one sidewall, an entire sidewall as illustrated in Figure 10I, portions of more than one sidewall (a preferred embodiment), or all of the sidewall area as illustrated in Figure 10J, forming a complete funnel (a particularly preferred embodiment). The resulting structure after plating is illustrated in cross section in Figure 10G. If the base is square, a perspective view of Figure 10G could resemble the view shown in Figure 10I.

For convenience of illustration, top plan views 10F and 10K show complete funnel embodiments, alternative to the partial funnel embodiments of detailed cross sections of Figures 10E, 10G and 10L. One skilled in the art will recognize that Figures 10F and 10K can be modified slightly to correspond to the specific embodiments of Figures 10E, 10G and 10L. A resulting structure would resemble a partial funnel, as shown in Figure 10I, with a circular base, as shown in Figure 10J.

Figure 10K is a top plan view of the electronic component of Figure 10G illustrating two of a plurality of contact structures 1060a and 1060b, each contact structure 1060a and 1060b associated with a one of two contact pads 1008a and 1008b (shown in dashed lines). The contact structures 1060a and 1060b each have a base end 1062a and 1062b, a tip end 1064a and 1064b and a central body portion 1066a and 1066b, respectively. The sloped regions 1063a and 1063b of the contact structures 1060a and 1060b, respectively, are illustrated in this figure.

As is evident in Figure 10K, the resulting contact structures are suitably tapered (widthwise) from wider at their base ends 1062a and 1062b to narrower at their tip ends 1064a and 1064b, respectively, in a manner comparable to the tapered contact structures shown and described in the aforementioned 08/852,152 application. The contact structures 1060a and 1060b are illustrated with double cross-hatching, for illustrative clarity, but it should clearly be understood that this double cross-hatching does not indicate a cross-section in this figure.

As is evident from the illustration of Figure 10G, the base end portion 1062, hence the entire contact structure 1060, is electrically connected to an associated one of the contact pads 1008 of the electronic component via the seed layer 1050 and the conductive layer 1010. As

is also evident, from the description set forth hereinabove, a group of the contact pads 1008 of the electronic component may be shorted to one another by the conductive layer 1010 to facilitate building up the contact structures 1060 by an electroplating process.

In final processing steps of the process, the masking layer 1020 can be removed, such as by washing it away with a suitable solvent. For example, a masking layer 1020 of photoresist can selectively be washed away with acetone, without adversely affecting other elements described hereinabove. And finally, all portions of the conductive layer 1010 that are not covered by another material (i.e., by the seed layer 1050) can selectively be etched away using appropriate chemistry.

Figures 10L and 10M illustrate, in cross-section and perspective views, respectively, the final product of a free-standing contact structure 1060 attached at its base end 1062 to an electronic component, its main body portion 1066 positioned away the surface of the electronic component 1002, and its tip end portion 1064 having a topography extending even farther from the level of the main body portion 1066. The sloped region 1063 of the base end 1062 of the resulting contact structure 1060 is clearly visible in these figures, as well as in Figures 10N and 10O, described hereinbelow.

In essence, for each contact structure 1060, an elongate mass of conductive material is deposited onto the masking material so as to have a base end 1062, a tip end 1064 opposite the base end 1062, and a main body portion 1066 between the base end 1062 and the tip end 1064. In a preferred embodiment, the main body portion 1066 is in a plane which is preferably approximately parallel to the surface of the substrate 1002 and which is offset (in the z-axis) from the base end 1062. The tip end 1064, as a result of the protruding feature 1030, is further offset from the main body portion 1066. When the masking material 1020 is removed, the resulting contact structure 1060 is free-standing, secured by its base end 1062 to the substrate 1002, with its tip end 1064 free to make contact with a terminal (e.g., 1070 or 1080) of another electronic component (e.g., 1072 or 1082, respectively, described hereinbelow).

### Third Exemplary Embodiment of a Resilient Contact Structure

A useful resilient contact structure can be made by other methods of material deposition, notably a direct deposition process such as sputtering, CVD, PVD and the like.

In one alternative embodiment, a desired shape is defined by a variety of elements. Referring to Figures 10A through 10D, an opening is defined in a masking material, and a protruding element may be added as well, as described in detail above. This forms a shape

upon which a suitable deposit can be made by direct deposition processes. The application of material can be controlled in a number of ways known in the art. Perhaps the simplest embodiment is to use a mask such as stencil 1040 with openings 1042 to limit where material may be deposited, generally as described above in the preparation of the seed layer 1050.

- 5 However, a suitable deposition material can be selected to allow deposition of an initial shaped deposit of suitable thickness to continue with the heat treating process as described in detail above.

Note that in sputtering a thick film the profile of the finished part will be affected by a number of variables that are understood in the art. In general a profile of a fully sputtered part will differ from the profile of a plated part such as that illustrated in Figure 10H. The  
10 exact profile will reflect deposition conditions, which include the directionality of the deposition process. In a highly oriented deposition process the profile will be generally rectangular. The sputtered part will tend to have a more rectangular cross section as material is built up at a generally similar rate across the opening 1042 in stencil 1040 and will continue  
15 to accumulate with a generally consistent width and generally consistent thickness. Collimation is one technique used to give a highly oriented deposition process. If the deposition process is not very oriented, the deposition process will tend to give a more rounded deposit. These parameters are well understood in the art. A cross section geometry can be predicted reasonably well, and masks and processes can be selected or modified to give  
20 a suitable cross section. In the course of making a resilient contactor, the profile of the part impacts the spring behavior so the profile can be considered in designing the desired spring shape. Such a design of springs is well within the skill in the art of mechanical engineering.

#### Materials And Processes

In a manner comparable to that of the 08/852,152 application, the contact structures of  
25 the present invention are principally, preferably entirely, metallic, and may be formed (fabricated) as multilayer structures. For purposes of the present invention of heat treating, the alloys and additives detailed above are preferred. Suitable materials for various other components of the structure include but are not limited to: nickel, and its alloys; copper, cobalt, iron, and their alloys; gold (especially hard gold) and silver, both of which exhibit  
30 excellent current-carrying capabilities and good contact resistivity characteristics; elements of the platinum group; noble metals; semi-noble metals and their alloys, particularly elements of the palladium group and their alloys; and tungsten, molybdenum and other refractory metals and their alloys. Use of nickel and nickel alloys is particularly preferred.

Suitable processes for depositing the material for the conductive layer (e.g. 1010), the seed layer (e.g. 1050), and contact structure (e.g. 1060) include, but are not limited to: various processes involving deposition of materials out of aqueous solutions; electrolytic plating; electroless plating; sputtering, chemical vapor deposition (CVD); physical vapor deposition (PVD); processes causing the deposition of materials through induced  
5 disintegration of liquid or solid precursors; and the like, all of these techniques for depositing materials being generally well known.

Suitable materials for the conductive layer include titanium-tungsten (Ti-W) which may be deposited by sputtering to a thickness of 3000-6000 Å, such as to a thickness of 4500 Å. An  
10 optional but preferred addition to the conductive layer is a layer of gold, which may be deposited to a thickness of 2500-4500 Å thick, for example 3500 Å thick. One important purpose of the conductive layer is to provide an electrical connection to the conductive trace(s) for the purpose of utilizing an electroplating process to deposit a mass of conductive material which will become the resulting contact structure on the seed layer. However, in one  
15 preferred embodiment the conductive layer is omitted. Another process such as electroless plating may be employed for depositing the mass of conductive material that will become the resulting contact structure. Yet another process such as sputtering may be employed for depositing the mass of conductive material.

The seed layer can be, for example, gold (Au) which may be deposited by sputtering  
20 to a thickness of about 2500-4000 Å. In another preferred embodiment, the seed layer is copper (Cu) which may be deposited by sputtering to a thickness of about 1000-3000 Å. Alternatively, the seed layer may another suitable material upon which the mass of the resulting contact structure can be deposited. Such materials include aluminum, Ti-W such as described for the conductive layer, palladium ink and graphite ink.

25 Note that a seed layer in certain configurations may be an elongate member. Note also that other elongate members, such as silicon, may be useful. Silicon in the form of a micromachined beam, as used in MEMS applications, is one useful example.

Suitable materials for the masking material (e.g. 1020) include a variety of lithographic photoresists, Novolac resin, and polyimide.

### 30 Compliance And Resilience

Figure 10N illustrates a case wherein it is desired to make a pressure contact connection between a tip end 1064 of a contact structure 1060 and a contact pad 1070 of another electronic component 1072 such as a printed circuit board (PCB). In this case, the

contact structure 1060 should react resiliently (i.e., elastically, rather than plastically) in the "z-axis" which is normal (at ninety degrees) to the surface of the substrate 1002. Such would be the case, for example, wherein it is desired to make socketable, readily removable, connections between the substrate 1002 and the electronic component 1072.

5        Figure 100 illustrates a case wherein it is desired to more permanently join, such as with solder 1084, the tip end 1064 of contact structure 1060 to a contact pad 1080 (compare 1070) of another electronic component 1082 (compare 1072) such as a printed circuit board (PCB). In this case, the contact structures 1060 should react compliantly in the "x-axis" and/or "y-axis", both of which are parallel to the surface of the substrate 1002. Such would  
10       be the case where it is desired to accommodate differences in thermal expansion coefficients between two electronic components.

The contact structure (1060) may react to applied forces by resiliently and/or compliantly deflecting in any or all of the x-, y- and z-axes. The improved material properties resulting from heat treatment can be utilized to provide a useful resilience in each axis.

15       Such a resilient contact structure can be enhanced by adding additional components. Copending, commonly assigned United States Patent Application S.N. 08/819,464, entitled "Contact Tip Structures for Microelectronic Interconnection Elements and Methods of Making Same", and corresponding PCT application S.N. PCT/US97/08606, published 20 November 1997 as WO97/43653, describes a method for defining a tip structure on a sacrificial substrate  
20       and transferring that structure to an electronic component. This tip structure can be transferred using the techniques described in that application to the structure of Figure 10L.

A general description of the device and method of using the present invention as well as a preferred embodiment of the present invention has been set forth above. One skilled in the art will recognize and be able to practice many changes in many aspects of the device and  
25       method described above, including variations which fall within the teachings of this invention. The spirit and scope of the invention should be limited only as set forth in the claims that follow.



**VI. CLAIMS**

What is claimed is:

1. A method of fabricating a resilient structure comprising the steps of  
providing an elongate member,  
5 depositing a coating on the elongate member to give a coated elongate member, the  
coating comprising at least one metal and at least one additive, and  
heat treating the coated elongate member at a combination of time and temperature that  
gives a coating with improved material properties.
- 10 2. A method of fabricating a resilient structure comprising the steps of  
providing an elongate member,  
depositing a coating on the elongate member to give a coated elongate member, the  
coating comprising at least one metal and at least one additive,  
the metal comprising a metal selected from the group consisting of nickel and  
15 cobalt, and the at least one additive selected from the group consisting of  
saccharin and 2-butyne-1,4-diol,  
and  
heat treating the coated elongate member at a combination of time and temperature that  
increases the yield strength of the coating.
- 20 3. A method of fabricating a resilient structure comprising the steps of  
providing an elongate member,  
depositing a coating as a metastable coating on the elongate member to give a coated  
elongate member, the coating comprising at least one metal and at least one additive,  
25 the at least one additive capable of codepositing with the at least one metal, and  
heat treating the coated elongate member at a combination of time and temperature to  
initiate a transition in the metastable coating to give a stable coating.
- 30 4. A method of fabricating a resilient structure comprising the steps of  
providing an elongate member,  
depositing a coating as a nanocrystalline material on the elongate member to give a  
coated elongate member, the coating comprising at least one metal and at least one

additive, the at least one additive capable of codepositing with the at least one metal,  
and

heat treating the coated elongate member at a combination of time and temperature to  
initiate a transition to give a coating comprising a crystalline material.

5

5. A resilient structure manufactured by the method comprising the steps of  
providing an elongate member,

depositing a coating on the elongate member to give a coated elongate member, the  
coating including at least one metal and at least one additive, and

10 heat treating the coated elongate member at a combination of time and temperature that  
increases the yield strength of the coating.

6. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the  
elongate member comprises a wire skeleton.

15

7. The method of claim 6 further comprising an electronic component with a contact pad  
wherein the wire skeleton is attached to the contact pad, wherein the electronic component  
may be a semiconductor device, semiconductor packaging, a semiconductor wafer, an  
electronic device for contacting one or more semiconductor devices, an electronic device for  
20 testing one or more semiconductor devices, a probe card, a probe, a connector, an interposer,  
or a socket.

8. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the  
elongate member comprises a sacrificial substrate.

25

9. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the  
elongate member comprises a sacrificial substrate coated with a seed layer of material to  
promote plating.

30 10. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the  
elongate member comprises a metal skeleton.

11. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the coating is formed by electroplating.
12. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the  
5 method of depositing the coating is selected from the group consisting of electroplating, chemical vapor deposition (CVD), physical vapor deposition (PVD), electrolytic or electroless aqueous solution plating of metals, and any process that causes deposition of materials through decomposition or reaction of gaseous, liquid or solid precursors.
- 10 13. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the coating is sufficiently thick that the heat-treated coating imparts resiliency to the coated elongate member.
14. The method of claim 1, 3 or 4 or the resilient structure of claim 5 wherein the at least  
15 one metal comprises a metal selected from the group consisting of nickel, cobalt, iron, rhodium, palladium, tungsten, copper, chromium, titanium, aluminum, gold and platinum.
15. The method of claim 1, 3 or 4 or the resilient structure of claim 5 wherein the at least one metal comprises a metal selected from the group consisting of nickel, cobalt and iron.
- 20 16. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 further comprising coating with a material including at least two metals, the two metals selected from the group consisting of Ni-Co, Co-Mn, Ni-Mn, Pd-Au, Pd-Co, W-Co, Ti-N and Ti-W.
- 25 17. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the coating comprises a Ni-Co alloy.
18. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 further comprising coating with a material including at least three metals, the three metals selected  
30 from the group consisting of Ni-Co-Mn and Ni-W-B.
19. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the at least one additive is a relatively minor component.

20. The method of claim 1, 3 or 4 or the resilient structure of claim 5 wherein at least one of the at least one additive or a derivative thereof is capable of codepositing with the at least one metal and is capable of coexisting with the at least one metal upon moderate heat treating to organize the structure of the coating to provide an increase in yield strength of the coated elongate member.
21. The method of claim 1, 3 or 4 or the resilient structure of claim 5 wherein the at least one additive comprises a sulfur-containing compound.
22. The method of claim 1, 3 or 4 or the resilient structure of claim 5 wherein the at least one additive is selected from the group consisting of saccharin, naphthalene-tri-sulfonic acid (NTSA), 2-butyne-1,4-diol, and thiourea.
23. The method of claim 2 further comprising using a plating bath for depositing the coating wherein the at least one additive is saccharin at a concentration in the plating bath of more than or equal to about 20 mg/L.
24. The method of claim 2 further comprising using a plating bath for depositing the coating wherein the at least one additive is 2-butyne-1,4-diol at a concentration in the plating bath of more than or equal to about 5 mg/L.
25. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 further comprising depositing the coating in the presence of a material selected from the group consisting of NiCl, NiBr, a Class 1 brightener and a Class 2 brightener.
26. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the coating undergoes an exothermic transformation in microstructure from a less organized to a more organized state, wherein the exothermic transformation has a peak temperature, and wherein the temperature of heat treating is between about 0° C above and about 100° C above the peak temperature.

27. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the coating comprises an amorphous material before the heat treating step.
28. The method of claim 27 wherein the heat treating step causes a transformation in the coating such that at least some of the amorphous material is transformed to an ordered material.
29. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the coating comprises an ordered material after the heat treating step.
30. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the coating comprises a nanocrystalline material before the heat treating step.
31. The method of claim 30 wherein the heat treating step causes a transformation in the coating of a significant portion of the nanocrystalline material to a crystalline material.
32. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the coating comprises a crystalline material after the heat treating step.
33. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 further comprising depositing the coating such that the coated elongate member is attached to a larger structure and comprises a resilient electrical contact.
34. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 further comprising removing the elongate member, in whole or in part, after the coating step and before or after the heat treating step.
35. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the elongate member comprises a material selected from the group consisting of gold, silicon, aluminum, copper, and titanium-tungsten.
36. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the coated elongate member has higher yield strength after heat treating than before heat treating.

37. The method of claim 36 wherein the heat treating is at a combination of time and temperature to give a coated elongate member with a yield strength near the maximum for that coating, such that significant further heat treating will reduce the yield strength significantly  
5 from that maximum.

38. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the coated elongate member is more resilient after than before heat treating.

10 39 The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the improved material property of the coating comprises increased yield strength compared with the yield strength of the coating before heat treating.

40. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the  
15 improved material property of the coating comprises increased elastic modulus compared with the elastic modulus of the coating before heat treating.

41. The method of claim 1, 2, 3 or 4 or the resilient structure of claim 5 wherein the improved material property of the coating comprises an increased stability under load at  
20 temperatures above 100°C compared with the corresponding stability of the coating before heat treating.

42. The method of claim 3 wherein the stable coating has a yield strength greater than that of the metastable coating.  
25

43. The method of claim 3 wherein the stable coating has an elastic modulus greater than that of the metastable coating.

44. The method of claim 3 wherein the stable coating is more resilient than the metastable  
30 coating.

45. The method of claim 4 wherein the crystalline material has a yield strength greater than that of the nanocrystalline material.

46. The method of claim 4 wherein the crystalline material has an elastic modulus greater than that of the nanocrystalline material.
- 5 47. The method of claim 4 wherein the crystalline material is more resilient than the nanocrystalline material.
48. A method of fabricating a structure comprising the steps of  
providing a base part, the part including a shape on which a first material can be  
10 deposited,  
depositing a first material on the shape to give an initial shaped deposit, the first material comprising at least one metal, and  
heat treating the initial shaped deposit at a combination of time and temperature to give a heat-treated, shaped deposit with improved material properties.
- 15 49. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the shape comprises a wire skeleton.
50. The method of claim 48, 84, 87 or 91 or the product of claim 95 further comprising an  
20 electronic component with a contact pad wherein the wire skeleton is attached to the contact pad, wherein the electronic component may be a semiconductor device, a semiconductor wafer, an electronic device for contacting one or more semiconductor devices, an electronic device for testing one or more semiconductor devices, a probe card, a connector or a socket.
- 25 51. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the shape comprises a space defined in a second material, the space contributing to the geometry of the heat-treated, shaped deposit.
52. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the shape  
30 comprises a second material coated with a layer of seed material to promote plating.
53. The method of claim 52 wherein the second material is selected from the group consisting of photoresist and wax.

54. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the initial shaped deposit is formed by electroplating.

5 55. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the method of depositing is selected from the group consisting of electroplating, chemical vapor deposition (CVD), physical vapor deposition (PVD), electrolytic or electroless aqueous solution plating of metals, and any process that causes deposition of materials through decomposition or reaction of gaseous, liquid or solid precursors.

10

56. The method of claim 48, 84, 87 or 91 wherein the heat-treated, shaped deposit is sufficiently thick that the improved material properties impart resiliency to the heat-treated, shaped deposit.

15 57. The method of claim 48, 87 or 91 or the product of claim 95 wherein the at least one metal comprises a metal selected from the group consisting of nickel, cobalt, iron, rhodium, palladium, tungsten, copper, chromium, titanium, aluminum, gold and platinum.

58. The method of claim 48, 87 or 91 or the product of claim 95 wherein the at least one  
20 metal comprises a metal selected from the group consisting of nickel, cobalt and iron.

59. The method of claim 48, 84, 87 or 91 or the product of claim 95 further comprising depositing a first material including at least two metals, the two metals selected from the group consisting of Ni-Co, Co-Mn, Ni-Mn, Pd-Au, Pd-Co, W-Co, Ti-N and Ti-W.

25

60. The method of claim 48, 84, 87 or 91 wherein the heat-treated, shaped deposit comprises a Ni-Co alloy.

61. The method of claim 48, 84, 87 or 91 or the product of claim 95 further comprising  
30 depositing a first material including at least three metals, the three metals selected from the group consisting of Ni-Co-Mn and Ni-W-B.



62. The method of claim 48, 87 or 91 or the product of claim 95 further comprising at least one additive in the initial shaped deposit where the at least one additive is a relatively minor component.

5 63. The method of claim 48, 87 or 91 further comprising at least one additive in the initial shaped deposit where at least one of the at least one additive or a derivative thereof is capable of codepositing with the at least one metal and is capable of coexisting with the at least one metal upon moderate heat treating to organize the structure of the heat-treated, shaped deposit to provide an increase in yield strength relative to the initial shaped deposit.

10

64. The method of claim 48, 87 or 91 further comprising at least one additive in the initial shaped deposit where the at least one additive comprises a sulfur-containing compound.

65. The method of claim 48, 87 or 91 further comprising at least one additive in the initial  
15 shaped deposit where the at least one additive is selected from the group consisting of saccharin, naphthalene-tri-sulfonic acid (NTSA), 2-butyne-1,4-diol, and thiourea.

66. The method of claim 48, 84, 87 or 91 or the product of claim 95 further comprising depositing the first material in the presence of a third material selected from the group  
20 consisting of NiCl, NiBr, a Class 1 brightener and a Class 2 brightener.

67. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the initial shaped deposit undergoes an exothermic transformation in microstructure from a less organized to a more organized state, wherein the exothermic transformation has a peak  
25 temperature, and wherein the temperature of heat treating is between about 0° C above and about 100° C above the peak temperature.

68. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the initial shaped deposit comprises an amorphous material.

30

69. The method of claim 68 wherein the heat treating step causes a transformation in at least some of the material of the initial shaped deposit from the amorphous material to an ordered material in the heat-treated, shaped deposit.

70. The method of claim 48, 84, 87 or 91 wherein the heat-treated, shaped deposit comprises an ordered material.

5 71. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the initial shaped deposit comprises a nanocrystalline material.

72. The method of claim 71 wherein the heat treating step causes a transformation in at least some of the material of the initial shaped deposit from the nanocrystalline material to a  
10 crystalline material.

73. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the heat-treated, shaped deposit comprises a crystalline material.

15 74. The method of claim 48, 84, 87 or 91 further comprising depositing the first material such that the heat-treated, shaped deposit is attached to the base part and comprises a resilient electrical contact.

75. The method of claim 48, 84, 87 or 91 or the product of claim 95 further comprising  
20 removing the shape, in whole or in part, after the depositing step and before or after the heat treating step.

76. The method of claim 75 wherein a first portion of the heat-treated, shaped deposit is secured to the base part and a second portion of the heat-treated, shaped deposit is separated  
25 from the base part such that, if unrestrained, it can move resiliently relevant to the base part.

77. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the shape comprises a material selected from the group consisting of gold, silicon, aluminum, copper, and titanium-tungsten.  
30

78. The method of claim 48, 84, 87 or 91 wherein the heat-treated, shaped deposit has higher yield strength than the initial shaped deposit.

79. The method of claim 78 wherein the heat treating is at a combination of time and temperature to give a heat-treated, shaped deposit with a yield strength near the maximum for that heat-treated, shaped deposit, such that significant further heat treating will reduce the yield strength significantly from that maximum.

80. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the improved material property of the heat-treated, shaped deposit comprises a selected, increased yield strength relative to the yield strength of the initial shaped deposit.

10

81. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the improved material property of the heat-treated, shaped deposit comprises a selected, increased elastic modulus relative to the elastic modulus of the initial shaped deposit.

82. The method of claim 48, 84, 87 or 91 wherein the improved material property of the heat-treated, shaped deposit comprises a selected, increased stability under load at temperatures above 100°C compared with the corresponding stability of the initial shaped deposit.

83. The method of claim 48, 84, 87 or 91 or the product of claim 95 wherein the heat-treated, shaped deposit is more resilient than the initial shaped deposit.

84. A method of fabricating a structure comprising the steps of providing a base part, the part including a shape on which a first material can be deposited,

depositing a first material on the shape to give an initial shaped deposit, the first material comprising at least one metal and at least one additive,

the metal selected from the group consisting of nickel and cobalt, and the at least one additive selected from the group consisting of saccharin and 2-butyne-1,4-diol,

30

and

heat treating the initial shaped deposit at a combination of time and temperature to give a heat-treated, shaped deposit with improved material properties.

85. The method of claim 84 further comprising using a plating bath for depositing the first material wherein the at least one additive is saccharin at a concentration in the plating bath of more than or equal to about 20 mg/L.

5

86. The method of claim 84 further comprising using a plating bath for depositing the first material wherein the at least one additive is 2-butyne-1,4-diol at a concentration in the plating bath of more than or equal to about 5 mg/L.

10 87. A method of fabricating a structure comprising the steps of

providing a base part, the part including a shape on which a first material can be deposited,

depositing a first material on the shape to give an initial shaped deposit which is a metastable shaped deposit, the first material comprising at least one metal, and

15 heat treating the metastable shaped deposit at a combination of time and temperature to initiate a transition to give a heat-treated, shaped deposit which is a stable shaped deposit and has selected material properties.

88. The method of claim 87 wherein the stable shaped deposit has a yield strength greater  
20 than that of the metastable shaped deposit.

89. The method of claim 87 wherein the stable shaped deposit has an elastic modulus greater than that of the metastable shaped deposit.

25 90. The method of claim 87 wherein the stable shaped deposit has increased temperature stability under load at temperatures above 100°C compared with the temperature stability of the metastable shaped deposit.

91. A method of fabricating a structure comprising the steps of

30 providing a base part, the part including a shape on which a first material can be deposited,

depositing a first material on the shape to give an initial shaped deposit which is a nanocrystalline deposit, the first material comprising at least one metal, and

heat treating the nanocrystalline deposit at a combination of time and temperature to initiate a transition to give a heat-treated, shaped deposit which is a crystalline deposit and has selected material properties.

5 92. The method of claim 91 wherein the crystalline deposit has a yield strength greater than that of the nanocrystalline deposit.

93. The method of claim 91 wherein the crystalline deposit has an elastic modulus greater than that of the nanocrystalline deposit.

10

94. The method of claim 91 wherein the crystalline deposit has increased temperature stability under load at temperatures above 100°C compared with the temperature stability of the nanocrystalline deposit.

15 95. A product manufactured by the method comprising the steps of  
providing a base part, the part including a shape on which a first material can be deposited,

depositing a first material on the shape to give an initial shaped deposit, the first material comprising at least one metal, and

20 heat treating the initial shaped deposit at a combination of time and temperature to give a heat-treated, shaped deposit with improved material properties.

96. The product of claim 95 wherein the heat-treated, shaped deposit is sufficiently thick that the improved material properties impart resiliency to the first material.

25

97. The product of claim 95 wherein the at least one metal comprises a metal selected from the group consisting of nickel, cobalt and iron.

98. The product of claim 95 wherein the heat-treated, shaped deposit comprises a Ni-Co alloy.  
30

99. The product of claim 95 further comprising at least one additive in the initial shaped deposit where at least one of the at least one additive or a derivative thereof is capable of

codepositing with the at least one metal and capable of coexisting with the at least one metal upon moderate heat treating to organize the structure of the heat-treated, shaped deposit to provide an increase in yield strength relative to the initial shaped deposit.

5 100. The product of claim 95 further comprising at least one additive in the initial shaped deposit wherein the at least one additive comprises a sulfur-containing compound.

101. The product of claim 95 further comprising at least one additive in the initial shaped deposit wherein the at least one additive is selected from the group consisting of saccharin,  
10 naphthalene-tri-sulfonic acid (NTSA), 2-butyne-1,4-diol, and thiourea.

102. The product of claim 95 wherein the heat-treated, shaped deposit comprises an ordered material.

15 103. The product of claim 95 further comprising depositing the first material such that the heat-treated, shaped deposit is attached to the base part and comprises a resilient electrical contact.

104. The product of claim 95 wherein the heat-treated, shaped deposit has higher yield  
20 strength than the initial shaped deposit.

105. The product of claim 104 wherein the heat treating is at a combination of time and temperature to give a heat-treated, shaped deposit with a yield strength near the maximum for that heat-treated, shaped deposit, such that significant further heat treating will reduce the  
25 yield strength significantly from that maximum.

106. The product of claim 95 wherein the heat-treated, shaped deposit has higher temperature stability than the initial shaped deposit, with increased temperature stability under load at temperatures above 100°C compared with the temperature stability of the initial  
30 shaped deposit.

107. The product of claim 95 wherein the heat-treated, shaped deposit is more resilient than the initial shaped deposit.

108. A structure with near maximal yield strength for such a structure, the structure comprising

an elongate member, and

5 a coating on the elongate member,

the coating comprising at least one metal,

treated to give a resilient structure with a selected yield strength, generally near the maximal yield strength for the composition of the coating as coated on the elongate member.

10

109. A structure with near maximal yield strength for such a structure, the structure comprising

an elongate member, and

a coating on the elongate member,

15 the coating comprising at least one metal,

treated to give a resilient structure with a coating comprising a predominantly crystalline structure.

110. A resilient contact structure with near maximal yield strength, the structure comprising

20 a base part,

a body connected to the base part, the body comprising in turn a first material,

the first material comprising at least one metal, and

wherein the body has been treated to give the body improved material properties.

25 111. A structure with predominantly crystalline grain structure, the structure comprising

a base part,

a body connected to the base part, the body comprising in turn a first material,

the first material comprising at least one metal and at least one additive, the at least one additive capable of codepositing with the at least one metal, and

30 treated to give a structure with a selected yield strength, generally near the maximal yield strength for the composition of the first material in the form of the body.

112. The structure of claim 108 or claim 109 wherein the elongate member comprises a wire skeleton.
113. The structure of claim 112 wherein the coating is at least as thick as the wire skeleton.
- 5 114. The structure of claim 112 further comprising a semiconductor with a contact pad wherein the wire skeleton is connected to the contact pad.
115. The structure of claim 108 or claim 109 further comprising an electronic component  
10 with a contact pad wherein the coating is connected to the contact pad.
116. The structure of claim 108 or claim 109 wherein the elongate member comprises a sacrificial substrate.
- 15 117. The structure of claim 108 or claim 109 wherein the elongate member comprises a sacrificial substrate coated with a seed layer of material to promote plating.
118. The structure of claim 108 or claim 109 wherein the elongate member comprises a metal skeleton.
- 20 119. The structure of claim 108 or claim 109 wherein the coating is formed by electroplating.
120. The structure of claim 119 further comprising at least one additive in the coating  
25 where the electroplating is performed in a bath which includes the at least one metal and the at least one additive.
121. The structure of claim 108 or claim 109 wherein the coating is formed by a process  
30 selected from the group consisting of electroplating, chemical vapor deposition (CVD), physical vapor deposition (PVD), electrolytic or electroless aqueous solution plating of metals, and any process that causes deposition of materials through decomposition or reaction of gaseous, liquid or solid precursors.



122. The structure of claim 108 or claim 109 wherein the coating is sufficiently thick to impart resiliency to the resilient structure.

5 123. The structure of claim 108 or claim 109 or the resilient contact structure of claim 110 or the structure of claim 111 wherein the at least one metal comprises a metal selected from the group consisting of nickel, cobalt, iron, rhodium, palladium, tungsten, copper, chromium, titanium, aluminum, gold and platinum.

10 124. The structure of claim 108 or claim 109 or the resilient contact structure of claim 110 or the structure of claim 111 wherein the at least one metal comprises a metal selected from the group consisting of nickel, cobalt and iron.

125. The structure of claim 108 or claim 109 further comprising at least one additive in the  
15 coating or the resilient contact structure of claim 110 or the structure of claim 111 further comprising at least one additive in the first material wherein the at least one additive or a derivative of the at least one additive is capable of codepositing with the at least one metal and is capable of coexisting with the at least one metal upon moderate heat treating to organize the structure of the coating to provide an increase in yield strength of the coated elongate  
20 member.

126. The structure of claim 108 or claim 109 further comprising at least one additive in the coating or the resilient contact structure of claim 110 or the structure of claim 111 further comprising at least one additive in the first material wherein the at least one additive  
25 comprises a sulfur-containing compound.

127. The structure of claim 108 or claim 109 further comprising at least one additive in the coating or the resilient contact structure of claim 110 or the structure of claim 111 further comprising at least one additive in the first material wherein the at least one additive is  
30 selected from the group consisting of saccharin, naphthalene-tri-sulfonic acid (NTSA), 2-butyne-1,4-diol, and thiourea.

128. The structure of claim 108 or claim 109 further comprising a coating comprising at least two metals, the two metals selected from the group consisting of Ni-Co, Co-Mn, Ni-Mn, Pd-Au, Pd-Co, W-Co, Ti-N and Ti-W.
- 5 129. The structure of claim 108 or claim 109 wherein the coating comprises an alloy.
130. The resilient structure of claim 129 wherein the coating comprises a Ni-Co alloy.
131. The structure of claim 108 or claim 109 further comprising a coating comprising at  
10 least three metals, the three metals selected from the group consisting of Ni-Co-Mn and Ni-W-B.
132. The structure of claim 108 or claim 109 further comprising at least one additive in the coating wherein the at least one additive is a relatively minor component.
- 15 133. The resilient contact structure of claim 110 or the structure of claim 111 further comprising a semiconductor with a contact pad wherein the body is connected to the contact pad.
- 20 134. The resilient contact structure of claim 110 or the structure of claim 111 further comprising an electronic component with a contact pad wherein the body is connected to the contact pad.
- 25 135. The resilient contact structure of claim 110 or the structure of claim 111 wherein the body is formed by electroplating.
136. The resilient contact structure of claim 135 further comprising at least one additive in the first material wherein the electroplating is performed in a bath which includes the at least one metal and the at least one additive.
- 30 137. The resilient contact structure of claim 110 or the structure of claim 111 wherein the body is formed by a process selected from the group consisting of electroplating, chemical vapor deposition (CVD), physical vapor deposition (PVD), sputtering, electrolytic or

electroless aqueous solution plating of metals, and any process that causes deposition of materials through decomposition or reaction of gaseous, liquid or solid precursors.

138. The resilient contact structure of claim 110 or the structure of claim 111 wherein the  
5 body is sufficiently thick to be resilient.

139. The resilient contact structure of claim 110 or the structure of claim 111 further  
comprising depositing a material including at least two metals, the two metals selected from  
the group consisting of Ni-Co, Co-Mn, Ni-Mn, Pd-Au, Pd-Co, W-Co, Ti-N and Ti-W.  
10

140. The resilient contact structure of claim 110 or the structure of claim 111 wherein the  
body comprises an alloy.

141. The resilient contact structure of claim 110 or the structure of claim 111 wherein the  
15 body comprises a Ni-Co alloy.

142. The resilient contact structure of claim 110 or the structure of claim 111 further  
comprising depositing with a first material including at least three metals, the three metals  
selected from the group consisting of Ni-Co-Mn and Ni-W-B.  
20

143. The structure of claim 108 or claim 109 further comprising a coating comprising a  
material selected from the group consisting of NiCl, NiBr, a Class 1 brightener and a Class 2  
brightener.

25 144. The structure of claim 108 or claim 109 further comprising at least one additive in the  
coating wherein the at least one metal and at least one additive or a derivative of the additive  
are organized in large part as an ordered material.

145. The structure of claim 108 or claim 109 further comprising at least one additive in the  
30 coating wherein the at least one metal and at least one additive or a derivative of the additive  
are organized in large part as a crystalline material.

146. The structure of claim 108 or claim 109 wherein the resilient structure comprises an electrical interconnection.

147. The structure of claim 108 or claim 109 wherein the elongate member comprises a material selected from the group consisting of gold, silicon, aluminum, copper, and titanium-tungsten.

148. The structure of claim 108 or claim 109 wherein the resilient structure has higher yield strength than a corresponding structure of a corresponding elongate member and a corresponding coating but without treatment.

149. The structure of claim 148 wherein the treating yields a resilient structure with a yield strength near the maximum for that coating on that elongate structure, such that significant further treating will reduce the yield strength significantly from that maximum.

15

150. The structure of claim 108 or claim 109 wherein the resilient structure has higher elastic modulus than a corresponding structure of a corresponding elongate member and a corresponding coating but without treatment.

151. The structure of claim 108 or claim 109 wherein the resilient structure has increased stability under load at temperatures above 100°C compared with the corresponding stability of a corresponding structure of a corresponding elongate member and a corresponding coating but without treatment.

152. The structure of claim 108 or claim 109 wherein the elongate member and coating is less resilient before treatment than after treatment.

153. The resilient contact structure of claim 110 or the structure of claim 111 further comprising depositing the first material in the presence of a third material selected from the group consisting of NiCl, NiBr, a Class 1 brightener and a Class 2 brightener.

30

154. The resilient contact structure of claim 110 or the structure of claim 111 wherein the body comprises an ordered material.

155. The resilient contact structure of claim 110 or the structure of claim 111 wherein the body comprises a crystalline material.

5 156. The resilient contact structure of claim 110 or the structure of claim 111 wherein the body comprises an electrical interconnection.

157. The resilient contact structure of claim 110 or the structure of claim 111 wherein the body is connected to the base part and comprises a resilient electrical contact.

10

158. The resilient contact structure of claim 110 or the structure of claim 111 wherein a first portion of the body is secured to the base part and a second portion of the body is separated from the base part but connected to the first portion of the body such that, if unrestrained, the second portion of the body can move resiliently relevant to the base part.

15

159. The resilient contact structure of claim 110 or the structure of claim 111 wherein the body comprises a material selected from the group consisting of gold, silicon, aluminum, and titanium-tungsten.

20 160. The resilient contact structure of claim 110 or the structure of claim 111 wherein the body has higher yield strength after being treated.

161. The resilient contact structure of claim 156 wherein the treating gives a resilient structure with a yield strength near the maximum for first material of the body, such that  
25 significant further treating will reduce the yield strength significantly from that maximum.

162. The resilient contact structure of claim 110 wherein an improved material property of the body comprises a selected, increased elastic modulus relative to the elastic modulus of the body before being treated.

30

163. The resilient contact structure of claim 110 wherein an improved material property of the body comprises a selected, increased stability under load at temperatures above 100°C compared with the corresponding stability of the body before being treated.

164. The structure of claim 111 wherein the body has a selected, increased elastic modulus relative to the elastic modulus of the body before being treated.
- 5 165. The structure of claim 111 wherein the body has a selected, increased stability under load at temperatures above 100°C compared with the corresponding stability of the body before being treated.
- 10 166. The resilient contact structure of claim 110 or the structure of claim 111 wherein the body is more resilient after the treatment.

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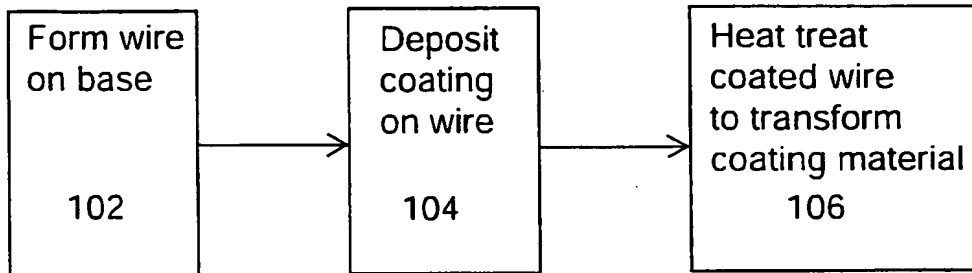


Figure 1

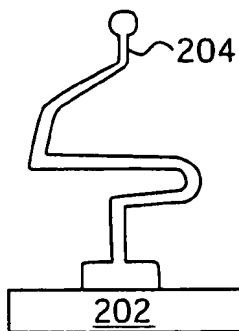


Figure 2A

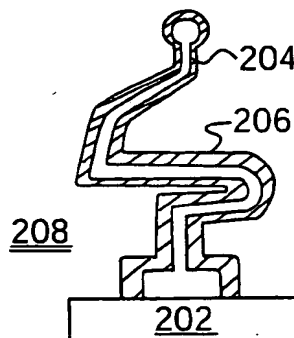


Figure 2B

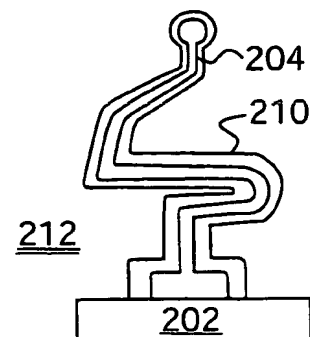
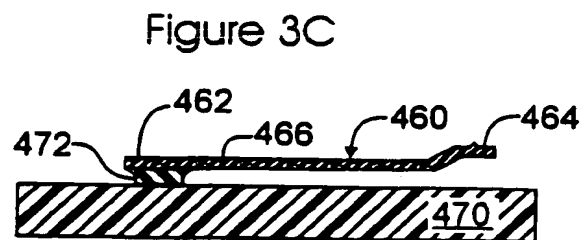
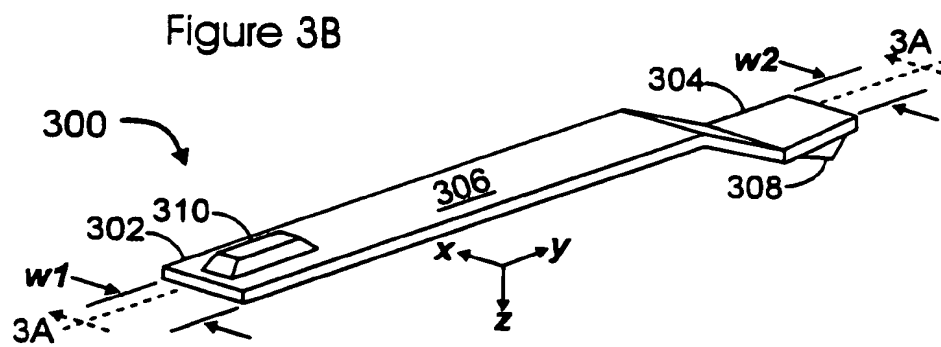
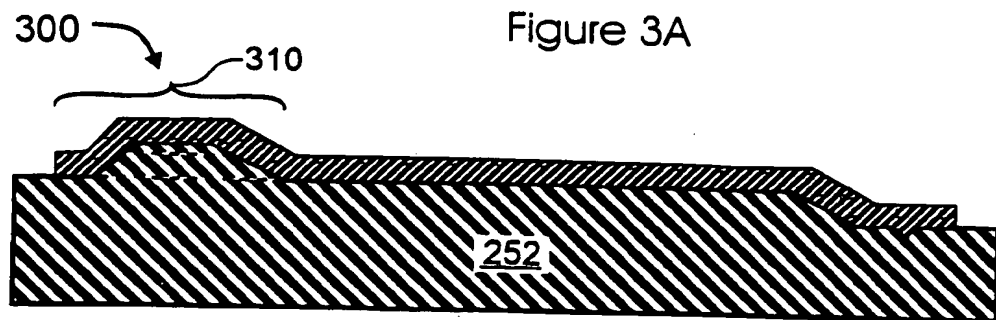


Figure 2C

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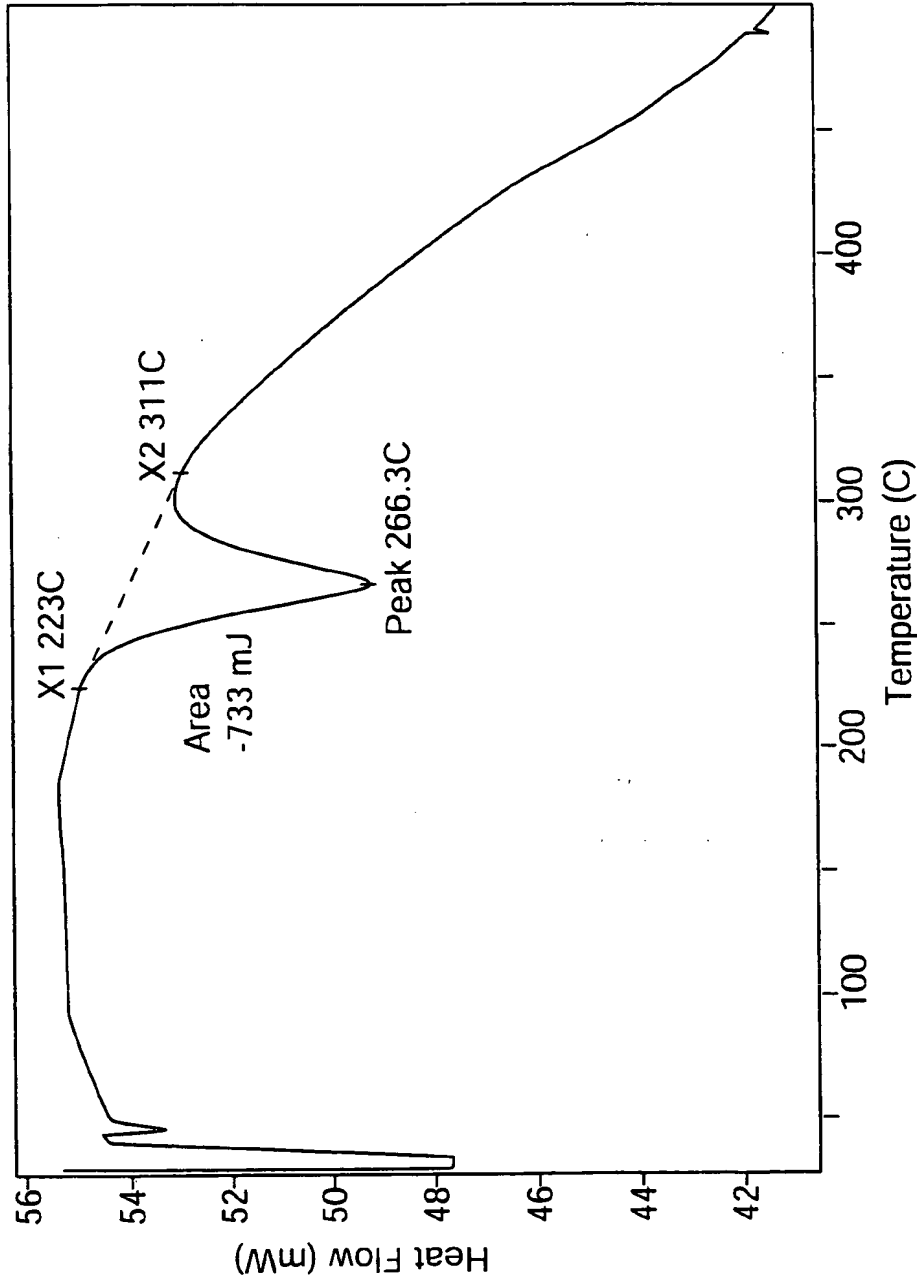


Figure 4

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## XRD Pattern for 50/50:Ni/Co Foil

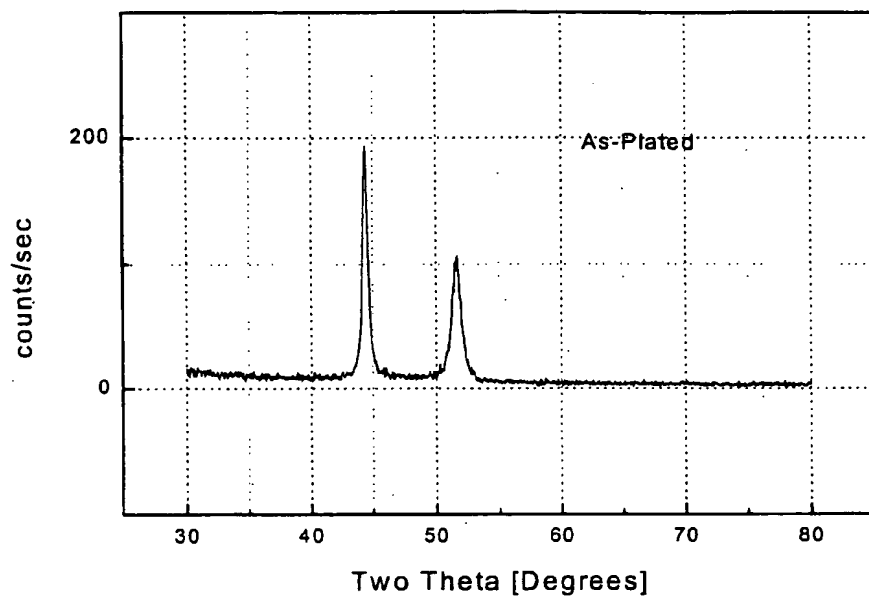


Figure 5A

## XRD Pattern for 50/50:Ni/Co Foil

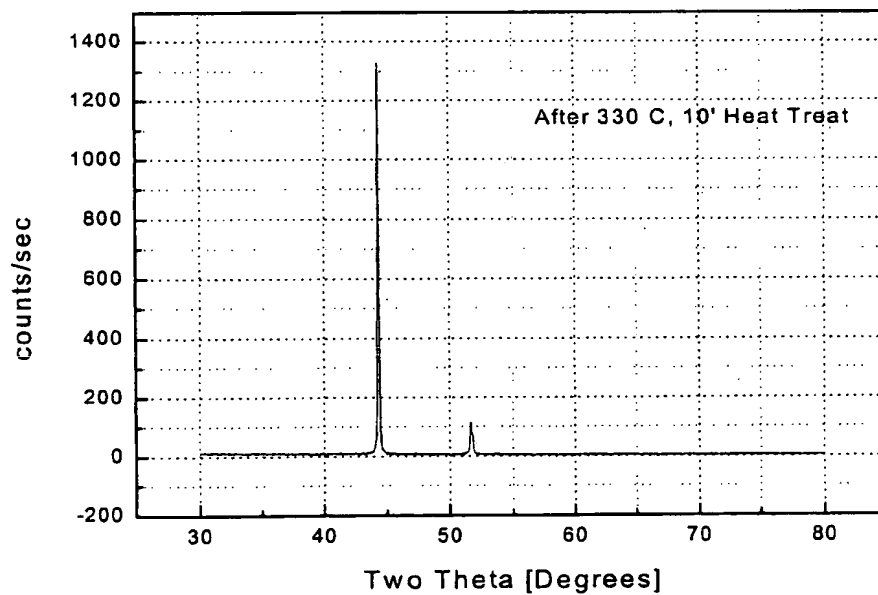


Figure 5B

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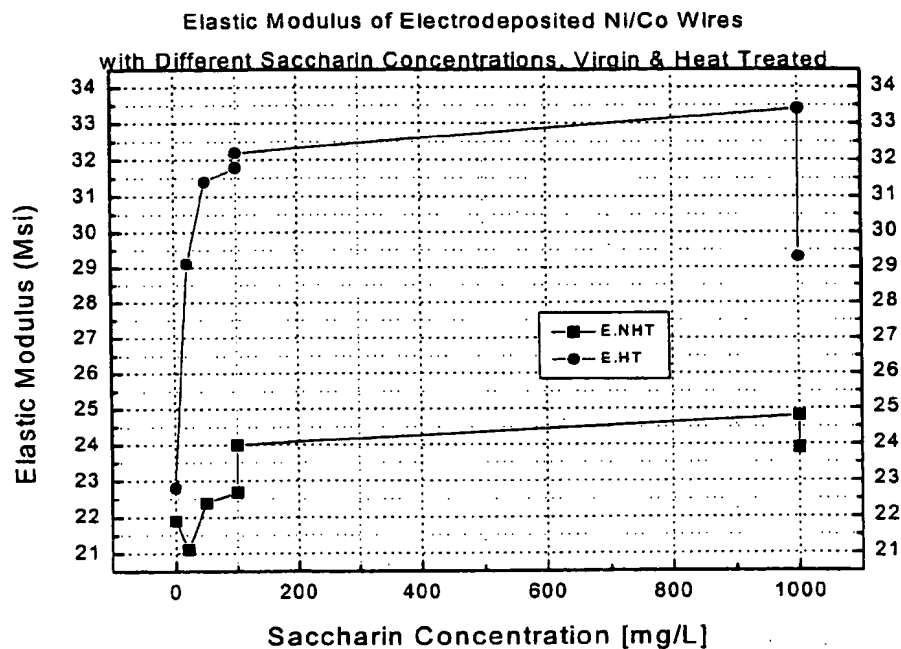


Figure 6

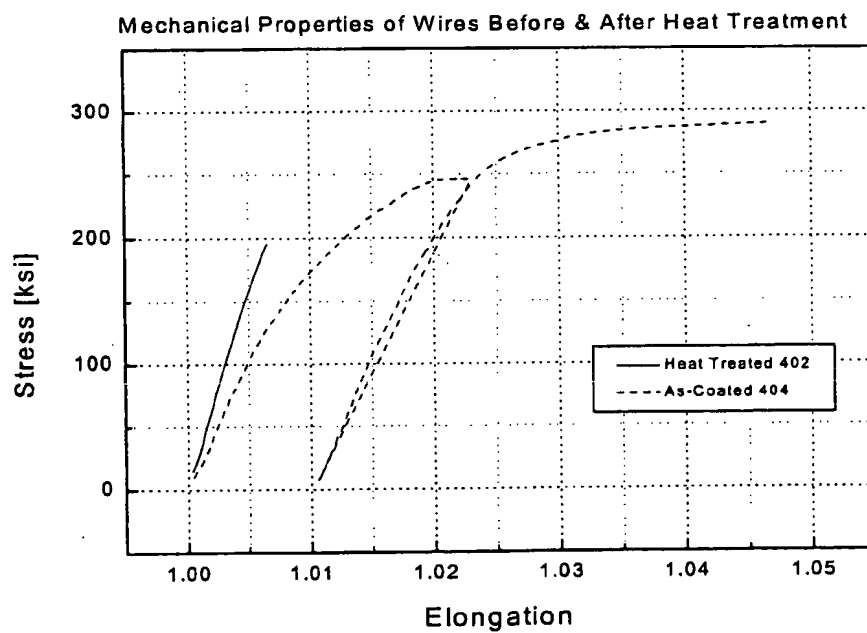


Figure 7

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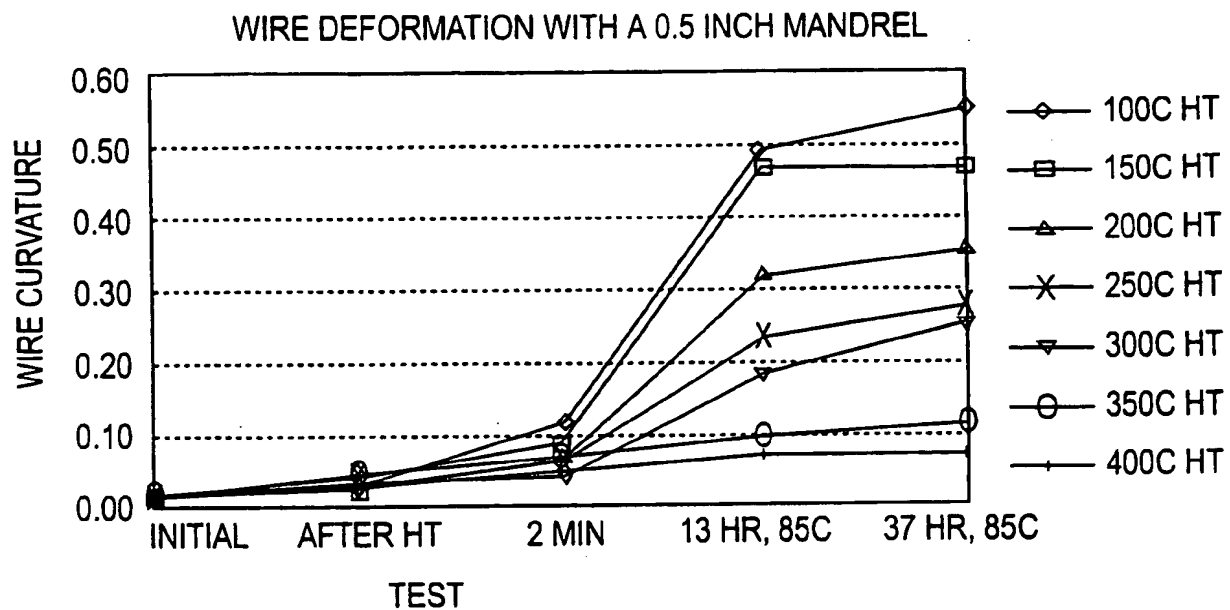
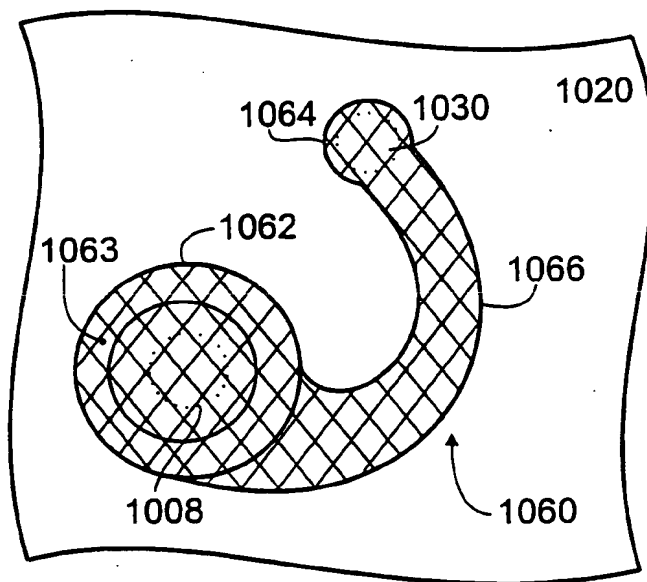


FIG. 8

FIG. 11



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Figure 9A

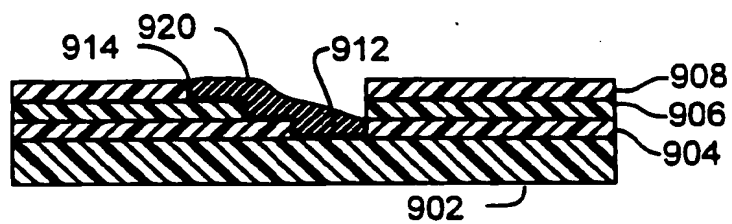


Figure 9B

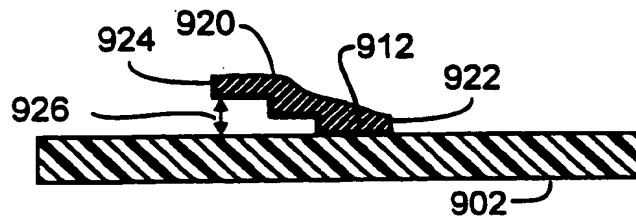
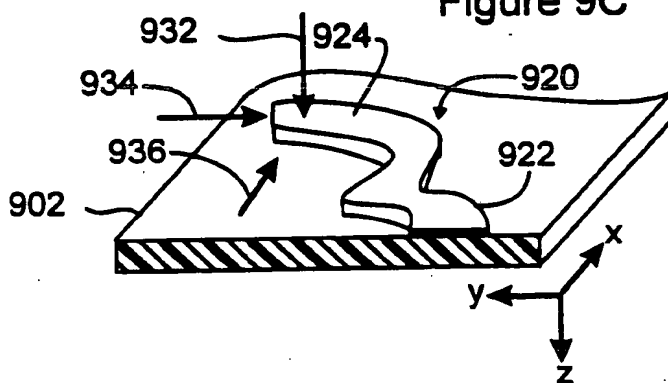


Figure 9C



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Figure 10A

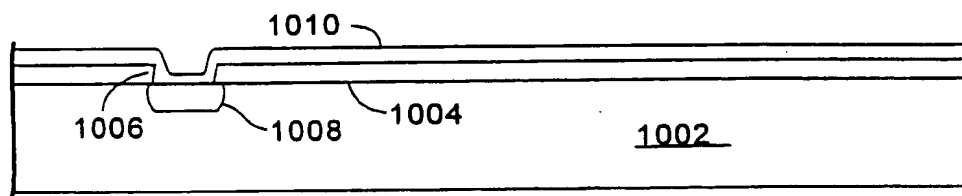


Figure 10B

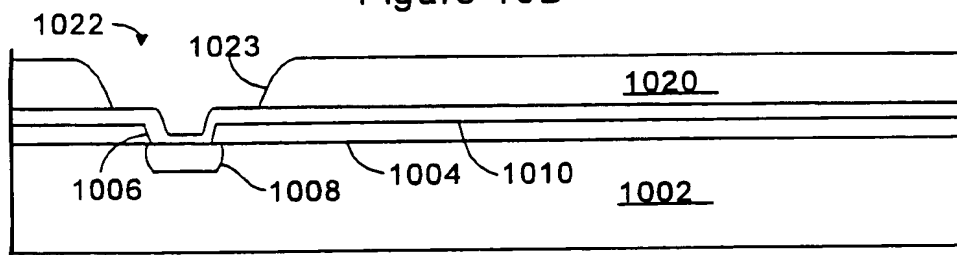
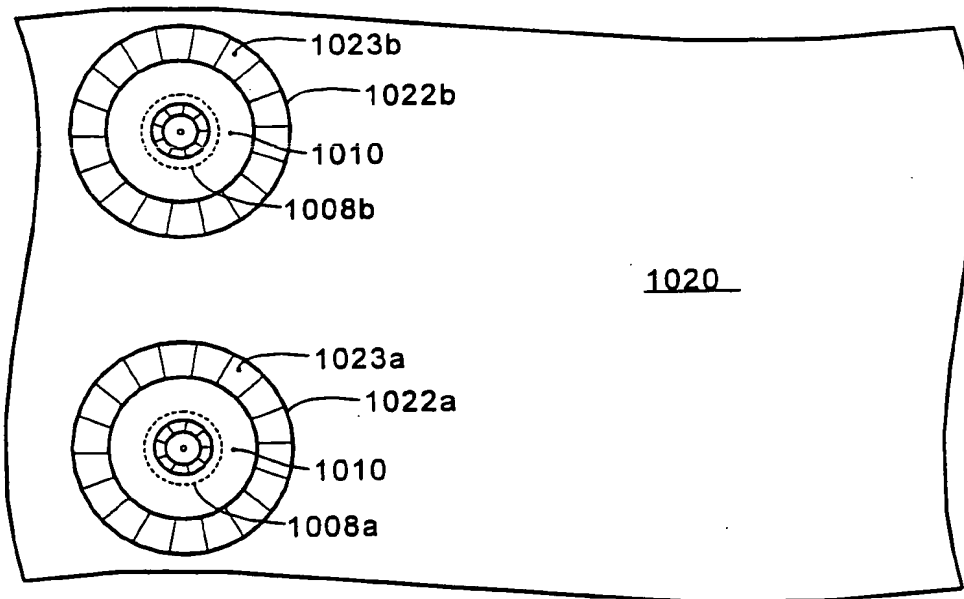


Figure 10C



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Figure 10D

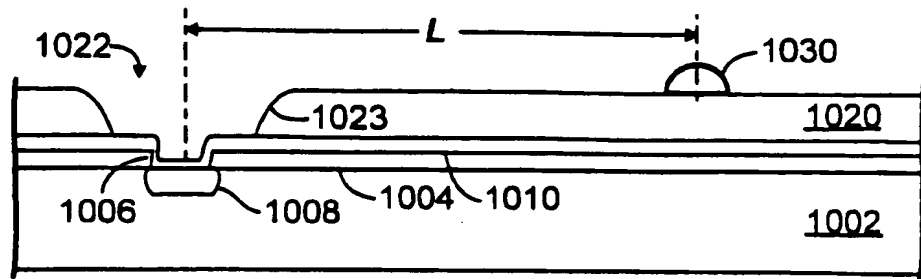


Figure 10E

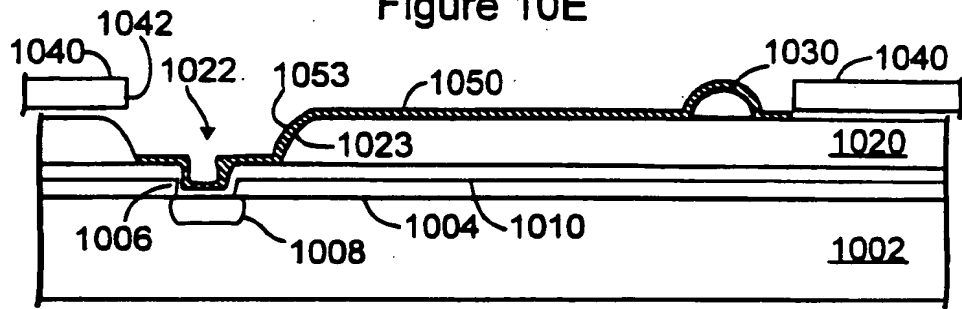
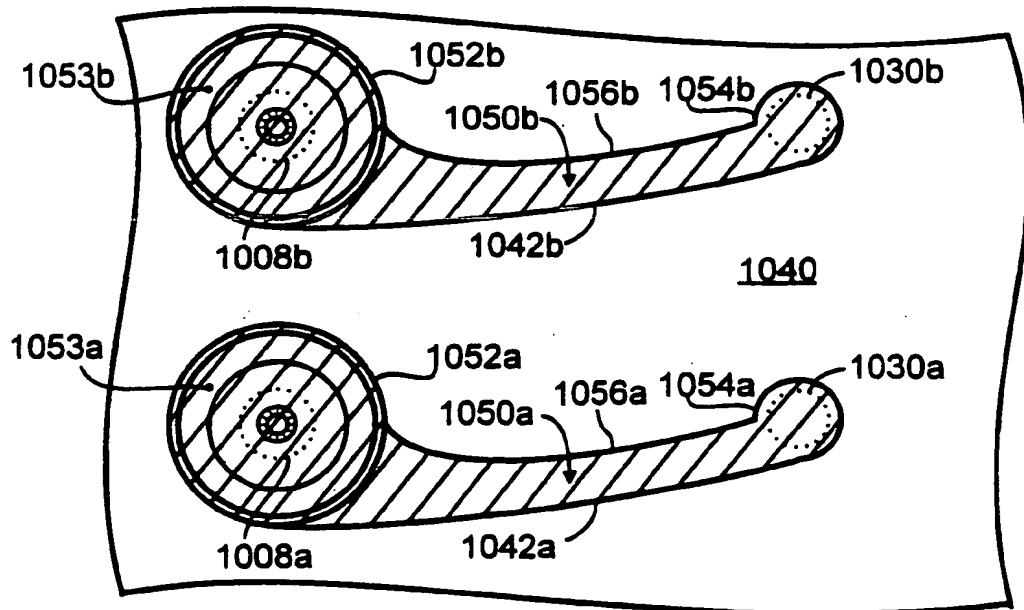


Figure 10F



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Figure 10G

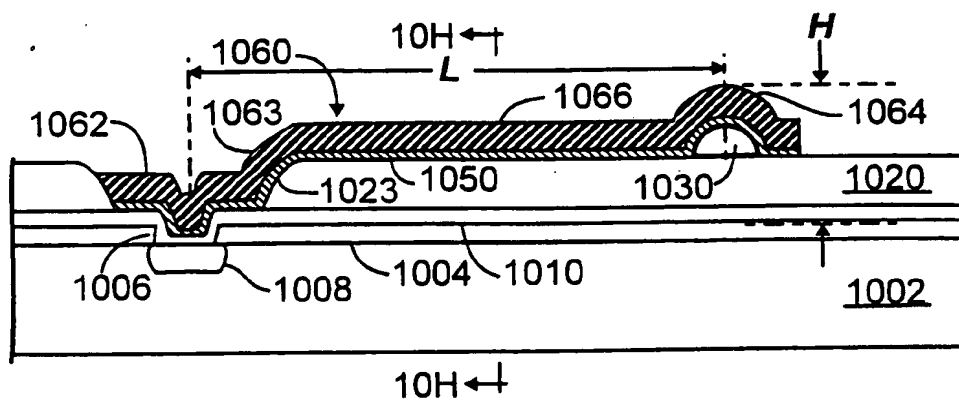


Figure 10H

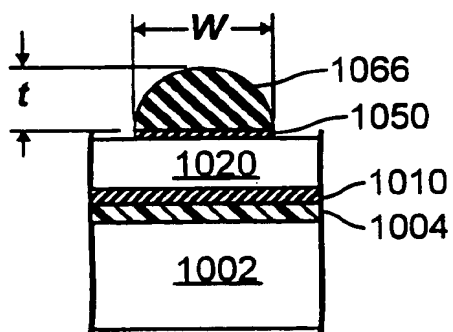


Figure 10I

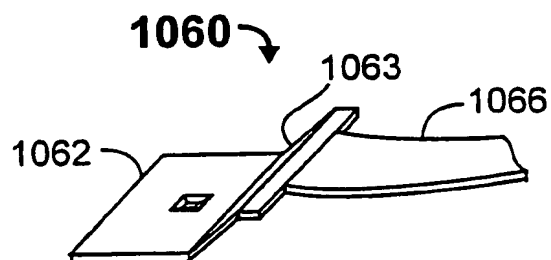
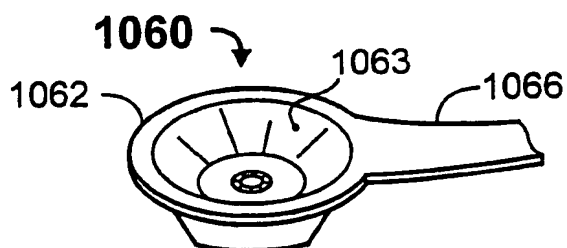


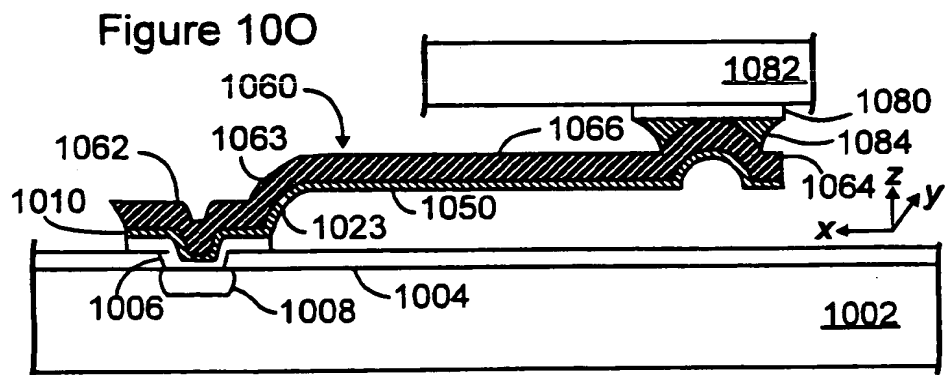
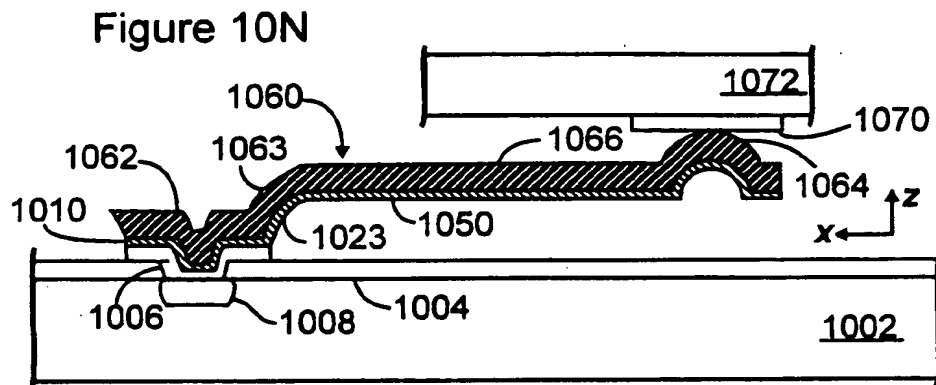
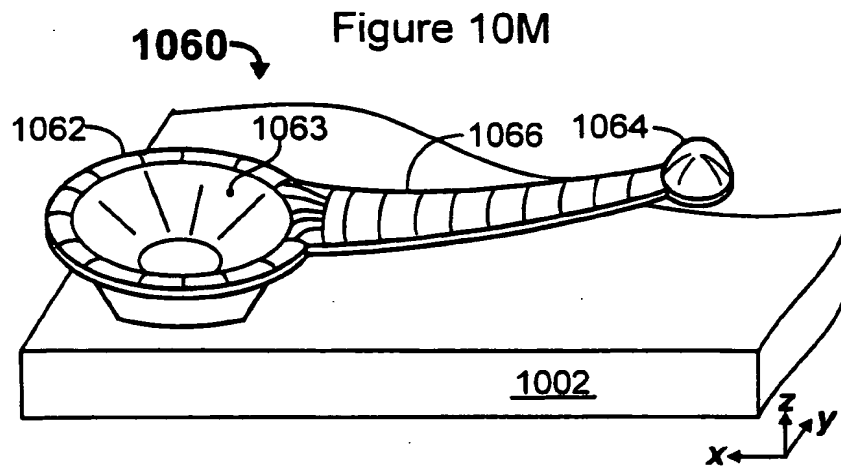
Figure 10J







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# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 98/12094

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 C25D7/00 H01L23/48

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 C25D H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 96 16440 A (FORMFACTOR INC) 30 May 1996 cited in the application ---	
A	DE 16 96 093 A (DRAHT UND FEDERNWERKE VEB) 4 November 1971 ---	
A	PATENT ABSTRACTS OF JAPAN vol. 014, no. 531 (C-0780), 21 November 1990 & JP 02 221377 A (TOYOTA MOTOR CORP; OTHERS: 01), 4 September 1990 see abstract ---	
A	DENNIS AND SUCH: "Nickel and Chromium plating", WOODHEAD PUBLISHING LTD, CAMBRIDGE XP002085098 see page 44-46 see page 363 - page 368 -----	

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

19 November 1998

Date of mailing of the international search report

04/12/1998

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Van Leeuwen, R

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